CFTRI-MYSORE
2960
Rice breeding an.

Scientific Monograph No. 19

ICAR. 12. 19.
775

सत्यमेव जयते

34

RICE BREEDING AND GENETICS

by

K. RAMIAH

Agriculture Officer, (Rice Expert) F.A.O.,
Formerly Director, Central Rice Research Institute, Cuttack, India ;

with the assistance of

M. B. V. N. RAO

Paddy Specialist, Madras, India

CENTRAL FOOD TECHNOLOGICAL RESEARCH INSTITUTE, * MYSORE. *
LIBRARY
17. 7. 54

The Indian Council of Agricultural Research
1953

~~2960~~
2960 / G 444
J ~~381:6~~
~~J3~~
J, 31:6;6
N53

CFTRI-MYSORE
2960
Rice breeding an..

FOREWORD

This Monograph covers a wide field for, apart from a thorough handling of rice breeding, genetics and cytology with which it is mainly concerned, it touches upon such a variety of topics as the origin and antiquity of rice, its classification, the wild rices and their affinity to cultivated types, the botany of the rice plant and the practical problems connected with the improvement of rice, such as quality of grain, vernalisation and hetrosis.

A complete study of all genetic studies on the rice plant is one of the most important features of this monograph. A very useful appendix gives a list of gene symbols which are recommended for adoption by all rice geneticists. Hitherto there has been much confusion owing to the lack of a standardised genic nomenclature, which the general adoption of the present list of symbols should do much to remove. Another appendix which fills a distinct gap in existing information, gives brief descriptions, in tabular form of all the improved strains of rice available in India. Last, but not least, reference must be made to the extensive bibliography of over 600 references.

By his long association with the rice research work of the well known Experimental Station at Coimbatore, the author is particularly well-fitted to deal with the subject he has chosen. His monograph brings together, as no other existing publication does, the work done on this subject in India up to date. For the student it is a very valuable work of reference and for the research worker it is no less useful in that it not only enables him to ascertain quickly the existing position in regard to the breeding and improvement of this, the most important food grain crop of India, but also makes useful and authoritative suggestions in regard to what remains to be done.

(H. R. STEWART)
Vice-Chairman,
Indian Council of Agricultural Research.

NEW DELHI,
25 *September* 1944

PREFACE

Rice is the most important food crop of India and occupies a predominant place in the agriculture of several provinces. The study of the rice plant and its cultivation has formed an important activity of the departments of agriculture in several provinces. Such a study extends to about three decades in Madras and Bengal where a Botanist was devoting his whole time attention to this crop. Similar work had also started somewhat later in Bombay and Assam but in other provinces regular breeding in rice had to wait until the Indian Council of Agricultural Research came into existence and started financing Rice Research Schemes.

Results of scientific interest, particularly, those relating to genetics of rice used to be published previously as Botanical Memoirs of Indian Department of Agriculture, and later as papers in the Indian Journal of Agricultural Science. There was still a good amount of useful information lying buried in the several annual reports of the agricultural research stations and departmental publications. Sir John Russel, who had come to India in 1936 at the invitation of the Indian Council of Agricultural Research, mentioned in his report ' There is considerable amount of good work in the vast mass of reports and it would be unfortunate if it all passed into oblivion. The best way of saving it would be the preparation of a critical monograph by a Specialist having a thorough knowledge of his subject. Much of the research in agricultural science done in India is not as widely known as it deserves to be, and I recommend the preparation of a series of monographs'. One of the subjects he had recommended for such treatment was Rice Breeding and Genetics, and this publication is the outcome of this recommendation.

All the available information on rice breeding and genetics in India has been brought together in this monograph. While it deals mainly with work in India, genetical results available outside India have also been included for easy reference. It is hoped that the publication meets the long-felt need for a connected account of the genetics of rice plant, and would prove of value to teachers and experimenters in agricultural institutes.

The authors would like to be excused if a reader of the monograph gets an impression that the Madras work has received greater prominence than that of any other province. Firstly, the authors are more familiar with Madras work than of other provinces and secondly, while in the case of other provinces they had to confine themselves to information available either in printed reports or personally communicated to them, in the case of Madras, they had access to the vast amount of unpublished data which the senior author had accumulated while he was Paddy Specialist there. With this consciousness they have tried to do full justice to material available outside Madras, but if they have not succeeded in their attempts it is mainly due to limitations mentioned above.

The authors have received considerable help in the preparation of this monograph from several sources and it is a pleasure to acknowledge such help. Several friends have read through the different chapters, in the manuscript and suggested valuable improvements. Of these, special mention might be made of Dr V. G. Panse, Director, Institute of Plant Industry, Indore, who had seen chapters VI, VII, VIII, IX, XII and XV. Similarly Dr N. Parthasarathy, Geneticist and Botanist, Indian Agricultural Research Institute, New Delhi, and Dr S. Ramanujam, Director, Central Potato Research Institute dealt with chapter XVIII, Dr B. S. Kadam, Director, Central Tobacco Research Institute with chapters XIII and XIV and Dr A. Sreenivasan of the University Department of Chemical Technology, Bombay, with chapter XIX. The author's thanks are due to all the above gentlemen. The several Rice Botanists in the provinces and States willingly cooperated in the undertaking by supplying all information and data available with them, and special mention has to be made in this connection of the unstinted and ready help received from the Paddy Specialist, Madras, in several directions.

Lastly, the senior author is grateful to the Indian Central Cotton Committee for permitting him to undertake the preparation of this monograph and to the Indian Council of Agricultural Research for entrusting the work to him and providing him with all facilities required.

RAMIAH

Indore, 1944.

ADDENDUM

The monograph was prepared over five years ago and due to various reasons the Indian Council of Agricultural Research could not get it published earlier. For purposes of economy the original manuscript has had to be revised twice, drastically cutting down the subject matter, figures and Plates. I have to acknowledge in this connection the great help I have received from Mr. R. L. M. Ghose, Geneticist and Botanist, Central Rice Research Institute in such revision. While the genetics of rice has been brought almost up to date, the other topics have been left as they were, dealing with undivided India since the publication is by the Indian Council of Agricultural Research and it was financing Rice Research Schemes all over India until the partition. In the original manuscript a small chapter had been included containing certain recommendations as to how future research in rice could be reorganised commensurate with the importance of the crop to India. This has now been dropped, but it may be mentioned that the establishment of the Central Rice Research Institute at Cuttack is the outcome of such recommendations.

CUTTACK,

April, 1950.

K. RAMIAH.

CONTENTS

PAGES

FORDWORD i

PREFACE iii

PART I

General

Chapter I.—Introduction 1

Chapter II.—Origin, Antiquity and Taxonomy of Rice 4

Chapter III.—Wild Rices and Species of Oryzae 7

Chapter IV.—Classification of Rice 10

Chapter V.—Botany of Rice Plant 14

Chapter VI.—Developmental Studies 24

Chapter VII.—Breeding Technique 28

PART II

Breeding of Rice in India

Chapter VIII.—Application of Genetics to the Improvement of Rice 35

Chapter IX.—Methods of Selection of Rice Followed in India 44

Chapter X.—Rice Growing Conditions and Practical Results of Breeding in India .. 49

Chapter XI.—Organization of Seed Supply 96

PART III

Genetics of Rice

Chapter XII.—Anthocyanin Pigment in Rice 104

Chapter XIII.—Inheritance of Morphological Characters 111

1. Root 111
2. Stem characters 111
3. Leaf characters 117
4. Chlorophyll deficiencies in rice 125
5. Characters of the panicle 131
6. Grain characters 154

Chapter XIV.—Inheritance of Physiological and Quantitative Characters 171

1. Sterility 171
2. Duration 178
3. Height 184
4. Tillering 186
5. Lodging of straw 187
6. Shattering of grain 191
7. Studies on flood resistance 196
8. Studies on drought resistance 200
9. Studies on resistance to salinity 203
10. Vernalization and photoperiodism 205
11. Relation of size of seed and crop resulting from it 210
12. Heterosis 212
13. Diseases of rice and breeding for disease resistance 215
14. Pests of rice 224

PAGES.
Chapter XV.—Correlations in Rice 229
Chapter XVI.—Linkage in Rice 237
Chapter XVII.—Mutations in Rice 247
Chapter XVIII.—Cytology of Rice and Wild Rices 257
1. Cytology of Rice 257
2. Interspecific hybrids and their cytology 263
3. Haploids, polyploids and polysomics in rice 266
Chapter XIX.—Quality in Rice 272
1. Agronomic factors affecting quality 273
2. Quality in relation to market value 273
3. Chemical composition of rice varieties 276
4. Nutritive qualities in rice 278
5. General conclusions 280
6. Present position 281
Chapter XX.—Problem of Rice Yield in India 284
REFERENCES 295

APPENDICES

Appendix I.—Description of Improved Varieties 312
Appendix II.—Genic Symbolization 355
Appendix III.—Glossary of vernacular names used 358
Appendix IV.—A laboratory method for determining cooking value of rice 359

LIST OF ILLUSTRATIONS

FIGURES FACING PAGES

1. Map showing distribution of area under rice in India viii
2. World's rice area and production 1
3. Map showing rice research stations in India and Burma 49
4. Section of weak and stiff straw 189
5. Anatomical structure of spikelet base 193
6. Somatic metaphase 259
7. Chromosomes of rice, cultivated and wild 263

PLATES

I Wild rices 2
II Variation in aleurone thickness .. ..
III *a* Nursery for bulk trials
b for single plants 28
IV Transplanting yield trial plots 29
V Harvesting trial plots 32
VI Method of artificial crossing in rice 33
VII Crop of Geb. 24 58
VIII Chanchala from Bombay 59
IX Parts of rice plant 103
X Ageotropic mutant 112
XI Variation in habit 113
XII Floating habit 114
XIII Internodes 115
XIV Leaf sheath 118
XV Leaf blade 121
XVI Chlorophyll deficiency 125
XVII Variation in density of panicle 133
XVIII *a*, Lemma and palea colours 138
b & *c* 140—142
XIX Polyembryony 153
XX Classification of grain 158
XXI Grain size variations from X-rayed Geb. 24 159
XXII Rice colour 160
XXIII X-ray sterile mutants 176
XXIV Height variation 177
XXV Anatomy of normal and flood resistant types 198
XXVI Treating seed for flood resistance 199
XXVII Exposing plants to light 208
XXVIII Resistant and susceptible type to *Piricularia* 209
XXIX Interspecific hybrids of *officinalis* × *sativa* 266
XXX Trispecific hybrid 267
XXXI Haploids and diploids 268
XXXII Diploids and tetraploids 269
XXXIII Polysomics 270

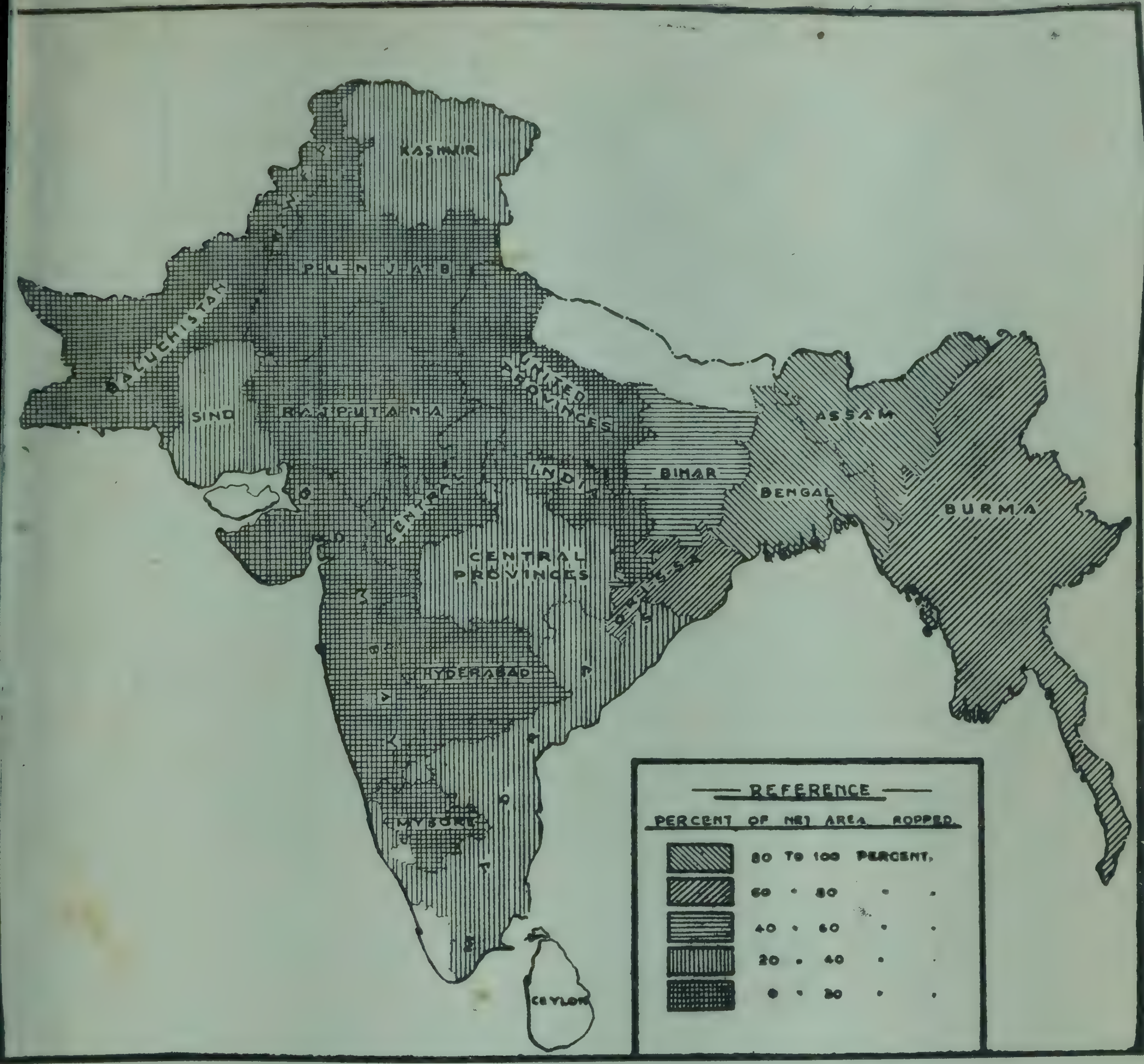

KASHMIR
PUNJAB
BALUCHISTAN
SIND
RAJPUTANA
UNITED PROVINCES
BIHAR
ASSAM
BENGAL
BURMA
CENTRAL INDIA
CENTRAL PROVINCES
ORISSA
HYDERABAD
MYSORE
CEYLON
REFERENCE
PERCENT OF NET AREA CROPPED
80 TO 100 PERCENT.
60 " 80 " "
40 " 60 " "
20 " 40 " "
0 " 20 " "

Fig. 1. Map showing distribution of area under rice in India.

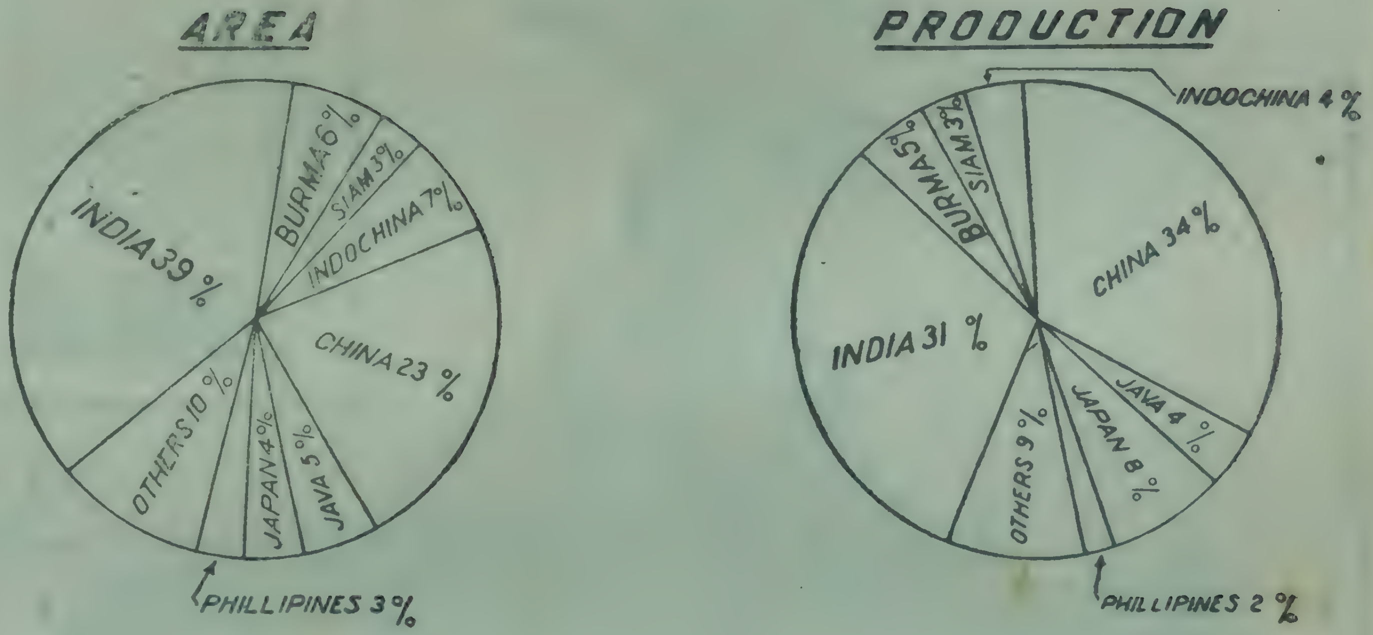


FIG. 2. World rice area and production.

(*Report—Rice **Marketing Survey**,* **1941**)

PART I—GENERAL

CHAPTER I

INTRODUCTION

RICE, wheat and maize, are the three most extensive food crops of the world. Rice forms the principal food of more than half the human race. The production *per capita* in some of the important rice growing countries is not enough to keep the population above want. The subcontinent of India comes under this category. While in normal times such deficits may be small and can be met by imports from countries with a surplus, in times of war, when grain cannot be imported, the position becomes serious. Considering the importance of this crop to India, there is enough justification for the claim that there is no other field in which well expended effort will add as much to human food and health as it will if applied to the improvement of rice. Unlike what has been done in the two crops, wheat and maize, in countries of the West, scientific work on rice in India has been largely fragmentary.

The statistics available for this crop are not as complete as those for certain other crops, such as wheat, but from the available figures it may be said that the world's production of rice has increased since the last thirty years. As compared to the total production of 50.4 million tons in 1909 (excluding China), the world's production in 1937, including China was 95 million tons, of which India's and China's contributions were 30.9 million and 31.5 million tons respectively. The acreage and production of rice in some of the important countries of the world are set out in Table I. It can be seen that nearly 95 per cent of world's rice area is concentrated in portions of the continent of Asia and the adjacent islands which are also densely populated (Fig. 2).

TABLE I

Area and production in important rice producing countries of the world

(Average of 1935-36 to 1944-45)

Country	Area (million acres)	Production of rice (million tons)	Calculated yield per acre (lb.)	Remarks
India	75·4	26·0	750	
China	45·7	34·1	1671	Production average for 7 years from 1935-36.
Indo-China	14·0	4·6	736	Production average for 7 years, area average for 5 years.
Burma	11·2	4·6	918	
Java	9·9	4·2	962	Production average for 9 years, area average for 6 years.
Siam	7·9	3·2	891	
Japan	7·8	8·0	2300	
Korea	3·7	2·5	1521	Area average for 9 years.
Philippines	4·7	1·5	723	Average for 7 years.
Formosa	1·6	1·1	1626	

Country	Area (million acres)	Production of rice (million tons)	Calculated yield per acre (lb.)	Remarks.
Ceylon	0·9	0·2	515	Production average for 8 years, area average for 7 years.
United States of America	1·2	0·7	1405	
Brazil	2·4	1·0	949	Production average for 5 years.
Italy	0·4	0·5	2813	
Spain	0·1	0·1	2688	Production average for 5 years from 1940-41.

Next to wheat and maize it is the third important food grain in international commerce. The countries with large deficits in this staple food are India, Japan and Ceylon and possibly China also. While Japan used to meet her deficits by imports from her dependencies, Korea and Formosa, other deficit countries got their requirements from Burma, Siam and Indo-China. Before Burma was separated from India in 1937, the export figures for rice from the Indian Empire obscured the actual position of India proper and tended to convey the impression that India's export of rice was very large. It was Burma that was contributing to this large export.

The area and production of rice in the provinces and States of India are given in Table II.

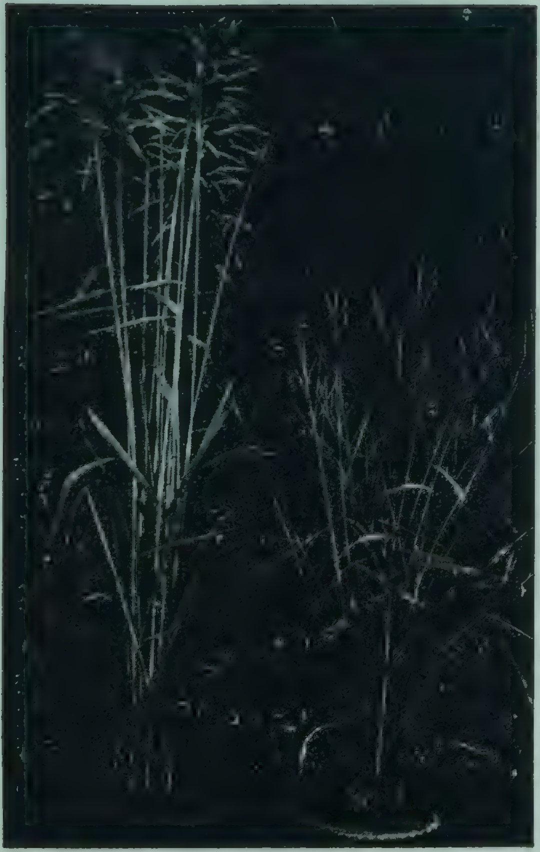
TABLE II

Area and production of rice, etc. in the several provinces and States of India

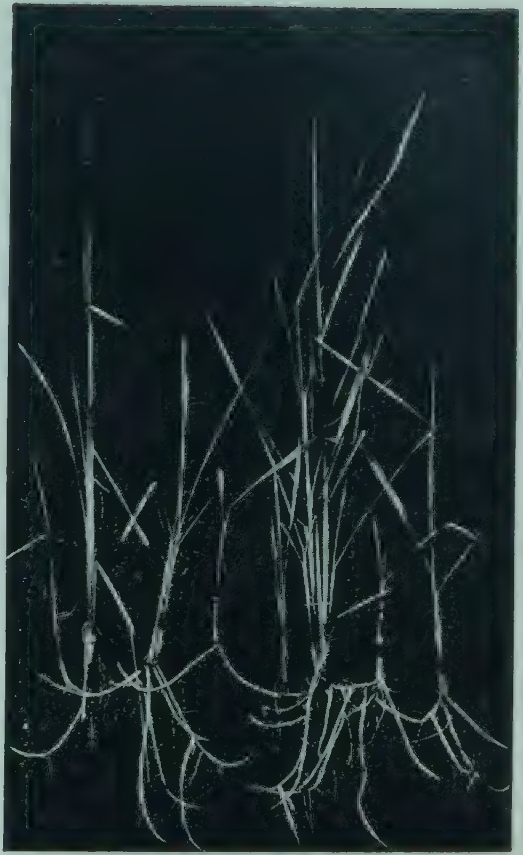
(Average of 1939-40 to 1945-46)

Province or State.	Area		Production		Percentage of area irrigated.		Calculated yield per acre (lb.)
	Million acres	Percentage on total area	Million tons	Percentage on total production	Total	Govt. canals	
Bengal	24·7	31·7	9·0	33·7	6·1	0·5	819
Madras	10·4	13·3	4·7	17·6	72·1	32·0	1011
Bihar	9·5	12·2	2·8	10·5	29·1	7·0	655
United Provinces	7·1	9·1	1·8	6·7	9·0	3·5	578
Central Provinces and Berar.	5·9	7·6	1·5	5·6	15·5	6·5	569
Assam	5·4	6·9	1·9	7·1	10·2	5·1	780
Orissa	5·1	6·5	1·3	4·9	16·3	5·0	589
Bombay	2·0	2·6	0·8	3·0	15·8	15·8	889
Sind	1·3	1·7	0·5	1·9	10·0	10·0	870
Punjab	1·1	1·4	0·4	1·5	77·8	77·8	751
Coorg	0·09	0·1	0·06	0·2	..	..	..
Eastern Agency States.	1·9	2·4	0·5	1·9	..	..	..
Hyderabad	1·1	1·4	0·4	1·5	..	..	..
Mysore	0·8	1·0	0·2	0·8	..	..	..
Travancore	0·7	0·8	0·6	2·2	..	..	..
Other States	0·9	1·2	0·3	1·0	..	..	..
Total India	77·95	100·0	26·7	100·0	..	..	..

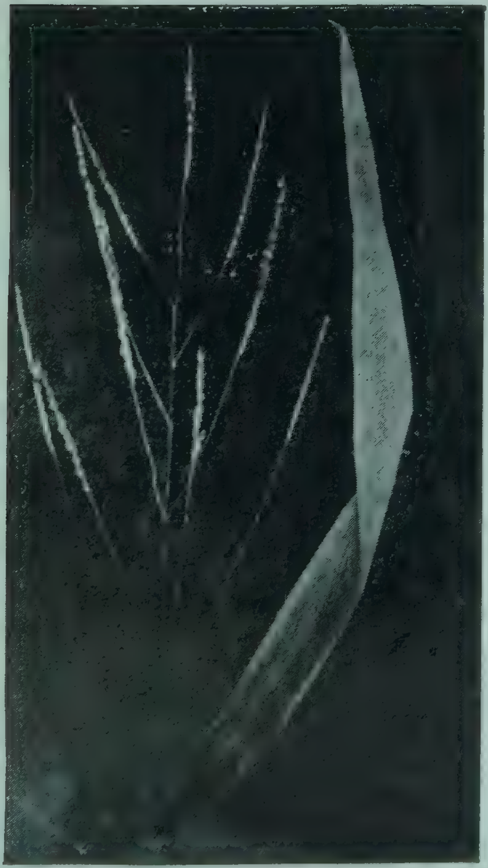
PLATE I



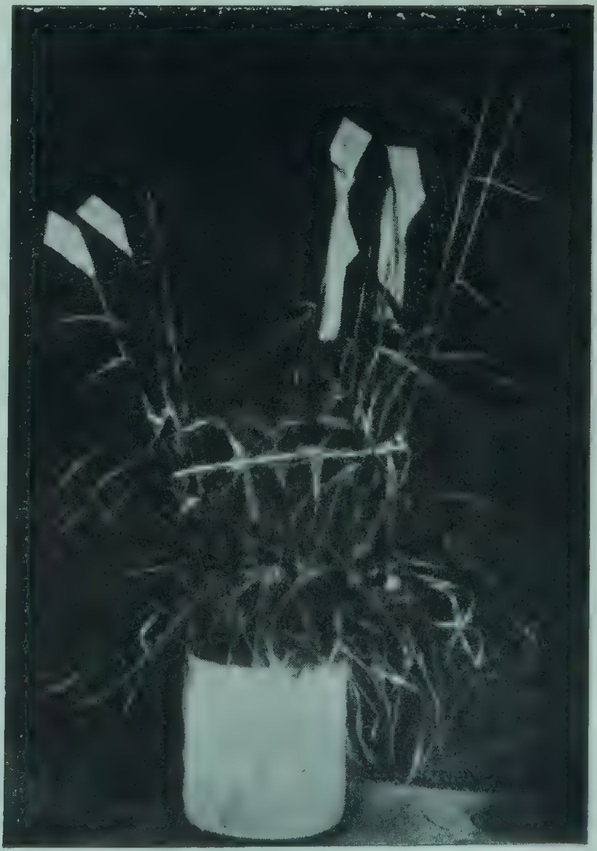
1 *O. officinalis* 2 *O. echingers*



3 *O. longistaminata*

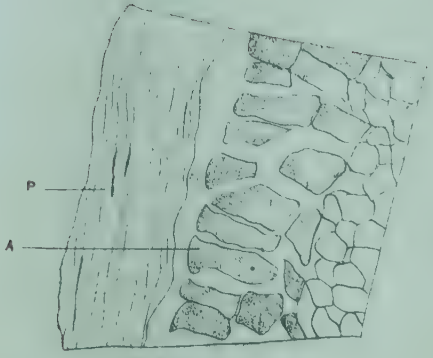


4 *O. latifolia*

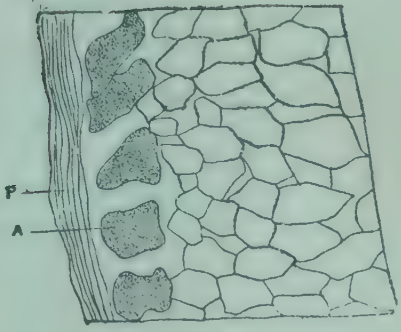


5 *O. minuta*

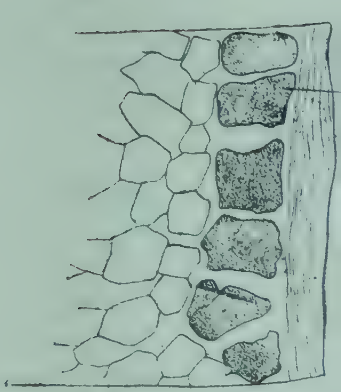
Some SPECIES of wild rice



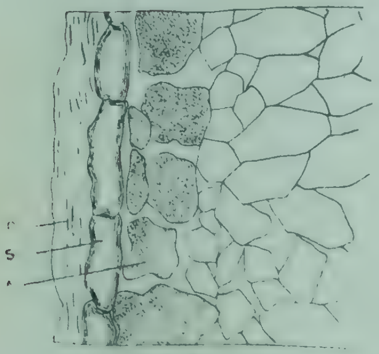
1 (White)



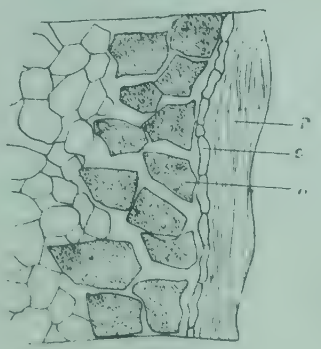
3 (Dark purple)



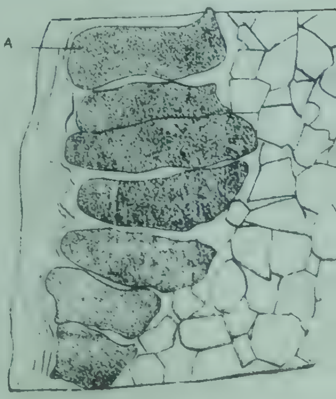
5 (Fine)



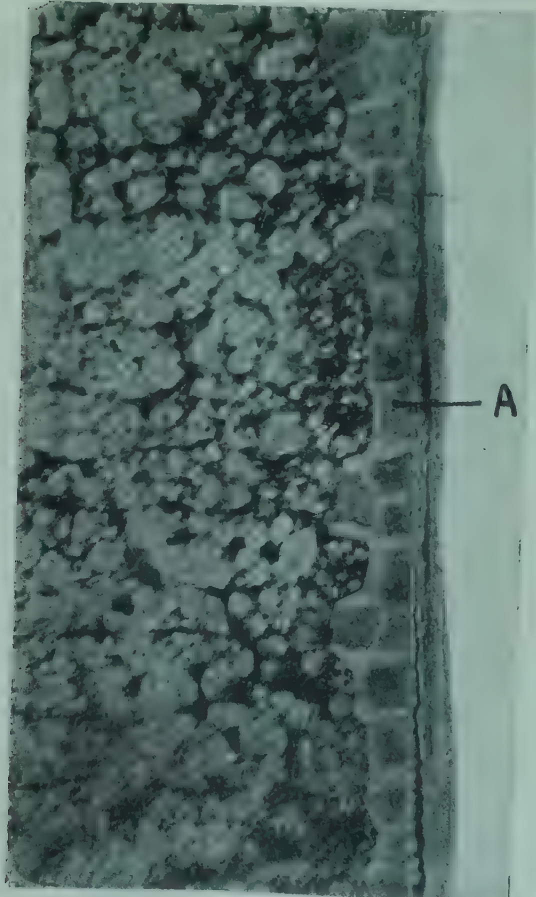
2 (Red)



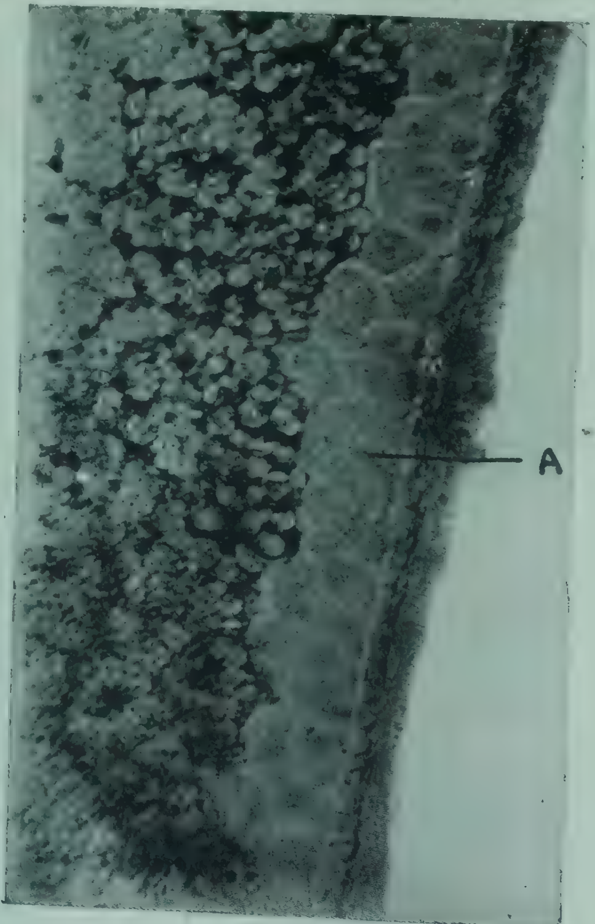
4 (Brown)



6 (Coarse)



7 (Manured, 4,000 lb- leaf)



8 (Manured, 10,000 lb. leaf)

Variation in aleurone thickness in rice grain

It can be seen that Bengal, Madras and Bihar are the most important rice producing provinces and among the States, Travancore, Hyderabad and Mysore occupy important positions. That India with nearly thirty per cent. of her cultivated area under rice is still not self-sufficient but has to import from outside, 5 to 8 per cent. of her requirements is a sad state of affairs. Since World War II imports have become impossible and the position is rather acute. That the country should be made at least self-sufficient with regard to her rice requirements does not require much emphasis.

In any attempt towards increasing the production in the country two ways are open ; (1) extension of area under the crop and (2) enhancement of yield per acre in the present area. Since a successful rice crop is dependent upon adequate irrigation facilities, extension of the area should mean undertaking of irrigation projects, and where possibilities for such projects exist there is no doubt it will prove an easy way of increasing production. Improvement of existing water facilities as in parts of Bengal and Bihar would also help to increase the present production. With regard to increasing acre yields in the existing rice areas there are two ways of achieving this end; (1) to evolve higher yielding varieties by scientific plant breeding methods and replace the existing varieties by such improved ones and (2) by changing the cultural and manurial practices that obtain at present. The intensive research of agricultural investigators in different parts of India during the last two decades has provided sufficient knowledge of the means of attaining increased acre yields by both these methods. Although there are reasons to believe that, of these two methods, the second one is more important and can give quicker and more tangible results, it is outside the scope of this monograph to deal with that aspect.

The cultural and manurial practices vary enormously from province to province and even to deal with the experimental results available on them in each province and State another monograph will have to be prepared. Ramiah [1937, b] has brought out in his popular hand book all the available results of such experiments that have gone on in the Madras Province during the last thirty years. Each of the important rice growing provinces may have to prepare a similar booklet dealing with the conditions of rice growing and the results of cultural and manurial experiments carried out there. Sethi [1940] has brought together some of the results of manurial experiments on rice conducted all over India and this requires revision.

Since the present monograph is entitled *Rice Breeding and Genetics* all the information available so far on these two subjects in the different provinces and States in India has been brought together. The plant breeding methods followed and the achievements have been dealt with in detail and suggestions made as to what remains to be done in particular directions. Since Burma was separated from India only in 1937 and since the Indian Council of Agricultural Research was actually financing a rice research scheme in that province until that time, the results from Burma have also been included briefly for the sake of completeness.

Though it might be said that the science of genetics has not played any important part in practical plant breeding achievements of earlier years, there is no doubt that it is bound to play an ever increasing important part in future work. In Madras, research on rice breeding and rice genetics has gone on side by side from the very beginning. All the available information on rice genetics has been brought together indicating here and there where lacuna exist in our knowledge.

CHAPTER II

ORIGIN, ANTIQUITY AND TAXONOMY OF RICE

RICE is probably the oldest of food crops. It has been in cultivation in China, India, Java and probably North Africa from very ancient times. In an ancient Chinese work it is recorded that the sowing of rice was an important religious ceremony nearly 5,000 years back. To the Emperor alone is said to have been reserved the privilege of sowing rice, the less important cereals being relegated to less exalted members of the family. It is mentioned that rice was one of the five principal plants nourishing the country, being of high economic importance even at that remote epoch. In India, ancient Hindu scriptures and literature bear ample evidence to the fact that rice was the chief offering to God. In some of the ancient Dravidian literature of South India, descriptions are to be found of particular varieties of rice which are to be used at particular religious offerings showing that even in those ancient times, varieties with definite grain characteristics were recognised. Susrutha [1,000 B.C. translation 1938] in his Ayurvedic *Materia Medica* recognised the differences among rices existing then in India and separated them into groups based upon their duration, water requirements and nutritional values.

Whether rice was introduced into India from China or it existed in India at the same time as in China cannot be accurately determined. It is probably as old in India as in China. There are records to show that rice was grown in Java as far back as 1084 B.C. It is likely that it went there from South India. It is from India that rice spread to Persia, Mesopotamia and Turkestan. According to Greek authors, rice penetrated into Europe by 300 B.C. first introduced by Alexander the Great from India, but the actual cultivation did not begin until the close of the seventh century. The introduction of rice into America is still later, towards the end of the seventeenth century.

Botanical research points out that every one of our cultivated crop plants must have originated from a primitive wild form existing in very ancient times and the improved forms now under cultivation must have gradually evolved from them by a series of steps. It has been possible to explain how the present cultivated forms of say, wheat or sugarcane, should have arisen, what the wild forms were from which they arose, and the original home from which they should have spread to different parts of the world. Such information about rice is still only a matter of speculation. De Condole [1886] supposed that cultivated species originated from where a similar wild form is found and concluded that India where a large number of wild forms are to be found must be the original home of rice. Watt [1892] records that the chief habitat of rice is to be found in South India, spreading east to Indo-China, which is characterised by marshy expanses, intervening mountains and periodical inundations which are the conditions most suitable for rice cultivation and therefore it must have started here first. Roschevicz [1931] after a comparative study of the several species of *Oryzae* and various forms of cultivated rice from herbarium specimens concludes that the cultivated rices arose first in South East Asia, namely, India and Indo-China, the conditions in these countries favouring mass mutations. Though the ancestry and origin of rice cannot be fixed with certainty, India together with Indo-China might well be the countries where cultivated rice first arose. The varietal diversity of rice is nowhere so great as in India and it is here that the species *O. sativa L. spontanea,* the nearest relative to the cultivated forms, occurs in abundance.

The questions of ancestry and place of origin of the cultivated plants are no longer of historical interest only. The researches of Vavilov and other Russian Botanists on the question of origin of cultivated plants have brought forth results not only of high scientific value but of practical help to the Plant Breeders. For determining the centre of origin, Vavilov takes into consideration the presence of wild allied forms and the existence of great diversity of forms. According to him, the longer a group has been established in a given area, the larger the number of species that are to be found there. Vavilov [1931] in his expeditions in Asia records that the south west part of the Himalayas is characterised by a wealth of forms and the rice varieties of this tract are allied to many of the Chinese varieties. This region might well be a centre of origin of the cultivated rice. Although no detailed studies have been undertaken, the wealth of forms present in the Agency tracts of Madras and Orissa is probably an indication that this area might form another independent centre of origin. Similar diversity to be found in the Philippines and Africa might indicate that these places could be other primary or secondary centres of origin of the cultivated forms.

The question arises how such a multitude of forms arise often in small areas. The first agency that works upon the primitive type is Nature itself. The various theories on evolution need not be repeated here as they are well known and can be looked up in any modern text book dealing with the subject. According to Timofeeff [1940] all types of morphological and physiological character changes are the result of mutations and these would form the evolutionary material. Special evolutionary factors are responsible for bringing about the gradual diversity of forms from an otherwise stable population. Recent researches have shown that large number of mutations do occur spontaneously in rice. The occurrence of mutations along with natural crossing both within the cultivated rices and between cultivated rices and *O. sativa L. spontanea* might be said to account for the great diversity in cultivated rices of India. Selective forces, both natural and human, have helped in the preservation of the most suitable forms for particular conditions of soil and climate.

Taxonomy

Oryzae, to which tribe the genus *Oryza* containing the varieties of cultivated rice belongs, is an isolated group in the *Gramineae* (comprising most of the food crops of the world) and it has not got any very obviously close connections with other tribes. In some respects as in having six stamens the genus *Oryza* can be considered primitive, while in others, such as the reduction of spikelets to one flowered condition, and of glumes to minute bodies, it has to be considered as an advanced genus. The genera of *Oryzae* are different from other grasses ecologically also, as all members of the genera except the species *Lygeum spartum* have become adapted to a hygrophilous or purely aquatic mode of life. Because of the peculiar mixture of advanced and primitive characters they have been differently classified by systematists. Some included them under *Panicoideae* while others classed them under *Pooideae.* Working on the multipistillate condition of a particular variety of rice and its association with other characters, Parthasarathy [1935] believes that this character must have evolved from the typical *Pooideae* spikelet by the suppression of the internodal rachis.

Oryzeae is classified into two sections by Hutchinson [1934], *viz.*, (1) *Oryzinae* including three genera, *Oryza, Leersia* and *Hygrorphiza* and (2) *Zizaninae* including the general *Zizania, Zizoniopsis, Hydrochloa* and *Luziola.* A cytological study of some species belonging to the several genera made by Ramanujam [1938] has justified the classification by Hutchinson. *Zizaninae* has a basic number of five chromosomes whereas the section *Oryzinae* shows a basic number of twelve. *Oryza* species shows either diploid or tetraploid complements. *Leersia* shows a tetraploid number and one species of *Hygrorhiza,* a diploid. It has been shown by cytologists that the basic number of twelve, in *sativa* at least, must have been derived from an original basic number of five by secondary polyploidy. It is likely that the chromosome complements in *Leersia* and *Hygroryza* have also developed from the basic number five.

With the establishment of basic chromosome number for *Oryzeae* as five, its closer relationship to *Panicoideae* than to *Pooideae* becomes evident. Several species of the tribe *Andropogoneae* of the sub-family of *Panicoideae* have five as their haploid complement and multiples of five. Their chromosomes are small and resemble those of *Oryzinae.* From the reduction of florets, suppression of glumes (the fertile glume being treated as lemma). and the possession of bicellular hairs in the epidermis as in *Oryza* and *Lygeum,* a caracteristic of *Panicoideae,* Ramanujam [1938] concludes that the *Oryzeae* genera suggest closer kinship to *Panicoideae* than to *Pooideae.* Parthasarathy [1939] has made cytological studies on some of the genera belonging to the *Phalarideae* tribe and concludes that three genera *Ehrharta, Microlaena* and *Tetrarrhena* have greater affinity to *Oryzeae* than to *Phalarideae* under which tribe they are generally included.

In recent years taxonomy of crops is developing a new method of approach. Until recently the taxonomist was more or less content with morphological studies; fertility or rather infertility on crossing was regarded as the sole criterion for taxonomic differentiation of species. But recent researches have shown that the species relationship has to be studied from more angles than one. Many groups universally recognised as different species by taxonomists are capable of fertile intercrossing while we find sterility in crosses between strains of obvious species. It has been brought to light by extensive studies of Vavilov and other Russian botanists that the so-called Linnean species are definite, discrete dynamic systems differentiated into geographical and ecological types and comprise sometimes an enormous number of varieties. Therefore the study of taxonomy is now being elaborated and it includes a synthesis of several branches of study like genetics, cytology, physiology, ecology and biogeography. As Vavilov [1940] suggests plant breeding requires for its purposes not only knowledge of morphological and botanical variations but also a knowledge of their differentiation into ecological and physiological groups. According to him the species is first divided into various ecological and geographical types corresponding to the *proles* of systematists; these geographical types (*proles*) may be divided for convenience into botanical varieties according to a few easily defined morphological characters and lastly, the botanical varieties are divided into *formas* which correspond to the commercial varieties of plant breeders.

CHAPTER III

WILD RICES AND SPECIES OF *Oryzae*

THE genus, *Oryza,* to which cultivated rices belong is a native of the tropics of both hemispheres, growing in wet places, the important species being *O. sativa* comprising of several distinct races of rice. All the cultivated rices grown in Asia, Europe and America belong to *O. sativa.* The next important species is *O. glaberrima* and includes varieties of cultivated rices grown in Africa. A thorough botanico-geographical survey of the genus has not been made and the available information regarding species and their distribution is still meagre. Cyto-taxonomic studies combined with cytogenetic investigations, which in modern times have been of great aid in the elucidation of phylogenetic developments have not proceeded far enough in respect to this genus. There exists, therefore, a considerable amount of confusion with regard to the proper classification of the species. Sometimes the same species is designated by different names, as for example, *O. barthii* and *O. longistaminata,* or two different species are given the same name, as for example, *O. latifolia* and *O. officinalis.*

Watt [1892] could identify five species of *Oryza* in India namely, *O. sativa L. spontanea, O. granulata, O. officinalis, O. mutica* and *O. nepalensis.* The polymorphism of wild rices was recognised by him and he divides *O. sativa L. spontanea,* the supposed immediate progenitor of the cultivated forms, into four varieties, namely, *O. sativa* var. *rufipogon, O. sativa* var. *coarctata, O. sativa* var. *benglalensis* and *O. sativa* var. *abuensis.* He considers that these wild rices have definite distinguishing features and believes that each of them has given rise to a separate group of cultivated rices. This is supported by the fact that not only the forms of cultivated rices vary greatly in morphological characters but they also maintain their diversified peculiarities under cultivation. *O. sativa* var. *rufipogon* is supposed by Watt to have given rise to the awnless, white-grained rices comprising the largest number of cultivated rices, and *O. sativa* var. *coarctata* to some coarse forms of the deep water and brackish water loving forms. *O. sativa* var. *bengalensis* may have been the progenitor of *aus, inter-aus* and *aman* rices of Bengal and other parts of India. The best and superior quality rices of Northern India and the hill rices have been, in his opinion, derived from *O. sativa* var. *abuensis* found in the valleys of Mount Abu in Rajputana. The above findings cannot, however, be accepted for the reason that *O. coarctata*, he groups as a variety under *O. sativa L.* var. *spontanea* although it is a tetraploid species having double the number of chromosomes.

The two main contributions to the systematics and distribution of *Oryza* species are from Roschevicz [1931] and Chevalier [1932]. About 25 species are known to occur in the wild state in India, Africa, Philippines, Java, Southern and Central America and islands lying close to it. Both the authors divide the genus into four sections *sativa, granulata, coarctata* and *rynchoryza* although the species included by them, in the various sections is not the same. According to Roschevicz, the first section consists of the following 12 species including *O. sativa L. spontanea* = *O. sativa L. fatua*

(Chevalier) which is widely spread covering the entire range of distribution of the genus :—

(1) *O. sativa* L. var. *fatua or spontanea*		India, Indo-China and other parts of Asia.
(2) *O. minuta*	Presl.	
(3) *O. officinalis*	Watt.	
(4) *O. punctata*	Kotschy	Africa.
(5) *O. longistaminata*	Chev.	
(6) *O. breviligulata*	Chev.	
(7) *O. glaberrima*	Steud.	
(8) *O. stapfii*	Rosch.	
(9) *O. schweinfurthiana*	Prod.	America.
(10) *O. latifolia*	Desv.	
(11) *O. grandiglumis*	Prod.	
(12) *O. australiensis*	Dom.	Australia

In addition to the above, the following fresh species have since been added to the list :

O. cubensis	Peter.
O. eichingeri	
O. barthii	Chev. (same as *O. longistaminta*)
O. formosana	
O. sylvestris	Stapf.
O. meyeriana	Bart. (probably same as *O. granulata*).
O. manilensis	

Roschevicz believes that *O. sativa* L. *spontanea* which occurs in Asia, Indo-China and North Australia, in places of most ancient and intensive rice cultivation and which itself comprises a number of forms, is the progenitor of most of the cultivated rices in India and Indo-China because of its resemblance to cultivated forms in several characters. He also believes that *O. breviligulata*, another member of this section, should have given rise to African cultivated rices, *O. minuta*, a third member to small fruited cultivated rices and *O. officinalis*, a still another member, to some of the Asiatic rices. He thinks that the wild species belonging to other sections of the genus have had no part in the origin of the cultivated rices. There is, however, not enough evidence to preclude altogether the possibilities of other wild rices being responsible for the origin of cultivated forms. That *O. sativa* L. *spontanea* has been the immediate progenitor of cultivated forms may be accepted. While the really wild species of *Oryza* do not either cross or do so with great difficulty in a few cases, *O. sativa* L. *spontanea* crosses very freely with cultivated rices. It occurs all over India and differs from the cultivated rices only with respect to habitat, growing habit and the ease with which the grains shatter. Where this species occurs as a weed in rice fields, hybrids are known to produce fertile offspring with various degrees of *spontanea* characters in them.

It is difficult to accept Roschevicz's opinion about the part played by *O. officinalis* and *O. minuta* with regard to the origin of cultivated types. The comparatively larger size of the chromosomes in *O. officinalis* than in the cultivated types probably does not support his view. Again his contention that *O. minuta* should have been the progenitor of small fruited cultivated forms does not appear valid for the reason that *O. minuta* is a tetraploid species with 48 chromosomes whereas all the cultivated small fruited rices so tar examined are only diploids. It is, therefore, probable that *O. minuta* is a younger species having resulted from interspecific hybridisation followed by doubling of chromosomes. This latter view is supported by Nandi [1938] and Morinaga [1938, a]. There are also certain other tetraploid species like *O. cubensis, O. latifolia* and *O. coarctata.* All these species might have presumably arisen through polyploidy. Until we have made a thorough investigation of the chromosome numbers of all the *Oryza* species and examined their relationship by interspecific crosses, any interpretation of phylogeny of the genus must remain doubtful. Up to now, only very few interspecific crosses have been made and studied.

Even the present designated species have to be examined whether they deserve a species status. *O. glaberrima* which is largely cultivated in Africa is very similar in morphological characters to *O. sativa* and it crosses readily with the latter. The glabrous nature of the species, on which the specific difference between the two species is based, has itself been found to follow a multiple factor segregation in crosses studied at the Paddy Breeding Station, Coimbatore. The position of certain other species, for example, *O. stapfii, O. grandiglumis* has got to be examined from this point of view. If the status of the latter as a distinct species is based only upon its having long elongated glumes, then it can be said that it does not deserve it as the size of the glumes, as has been shown elsewhere, is governed by one or two genes. Hence a more comprehensive and systematic study of the genus in all its aspects is called for before a thorough understanding of the problem of the origin and evolution of rice is possible.

Since seven out of the twelve species of the section *sativa* are found distributed in Africa as against only three in Asia, Roschevicz thinks that the centre of origin of this section must be Africa and not Asia. This conclusion of his must remain tentative until a more thorough exploration of India and other eastern countries is made for a *Oryza* species. So far as India is concerned, besides the three species mentioned by Roschevicz, other species that are now known to occur are *O. granulata* in the Nilgiri Hills of South India, *O. longistaminata* in the jhils of Bengal and Orissa and *O. coarctata* (Roxb.) in the estuaries of the rivers, Ganges and Indus. Watt has already referred to the first and the third. In addition, *O. glaberrima, O. barthii* and *O. stapfii* are said to occur in North Western Provinces. Although the species *O. sativa* L. *spontanea* occurs all over India from the extreme south of the peninsular India up to the foot of the Himalayas, no systematic collection nor a comparative study of the forms has yet been made. It is possible such a study might bring to light a greater number of distinct races not recognised hitherto. Botanical expeditions into some of the special centres such as the North Western India at the foot of the Himalayas, a similar region near the North Eastern India, Assam and mountaneous regions on the eastern side in Orissa and peninsular India might bring out still other species of *Oryza*. Collecting and making a comparative study of the wild species of *Oryza* in India should make an extremely useful and valuable line of work for any university Department of Botany in India. Chatterjee [1947] has very recently taken up the study of wild and cultivated rices and he lists 23 as real species, but he has not made use of the available cytological knowledge.

CHAPTER IV

CLASSIFICATION OF RICE

AS has been mentioned already all the cultivated rices in India have been classified under one species, *O. sativa.* It has been recorded that more than 8,000 botanically different varieties are in existence in the world today of which more than 4,000 have been identified in India. Amongst the several cultivated rices two major groups or races are discernible : (1) *O. sativa* forma *indica* group belonging to the tropical zones and (2) *O. sativa* forma *japonica* group confined to the more northern sub-tropical conditions. The former group comprises all the cultivated rices of India, Indo-China, the Philippines, Southern China, etc., and all the varieties indigenous to Japan, Korea (Chosen) and Northern China belong to the second group. This second group also includes the American, Italian and Spanish rices which were all originally obtained either from Japan or North China. Some varieties of the *japonica* group are also to be found in Burma and Java and these should be later introductions. Even in the United States of America, while the rices grown in California belong to the *japonica* group, those grown in the southern States, are either *indica* or derivatives of hybrids of *indica* with *japonica.*

The chromosome complement in both the groups is the same, the haploid number being twelve. In the F_1 generation of crosses between the two races there are 12 bivalents indicating that the structural differences in the chromosomes are not so great as to prevent pairing, Sakai [1935] and Parthasarathy [1938] have found that the *japonica* type has a single pair of SAT chromosomes while the *indica* group has two pairs, corresponding to the number of the nucleoli present in each.

The fact that a marked degree of sterility accompanies when these two groups are crossed with each other may, in part, justify their differentiation. In the F_1 generation of the cross between varieties belonging to *japonica* and *indica* races studied by Jones [1930, b] the degree of sterility varied from 28.9 to 83.6 per cent whereas it did not exceed 9.6 per cent in the F_1s_2 of crosses within each group. In addition to the sterility observed, the development of the plants was also abnormal, in that a large number of F_2 plants were so late that they failed to head and those which flowered failed to set normal seed. It is reasonable to suppose that the sterility and lateness are due to incompatibility in the chromosomes of the two races brought about by accumulation of gene mutations that might have occurred during their long period of separation from each other. This hypothesis gains support from the recent studies on geographical races of other crop plants by the Russian Botanists.

It is not surprising to find considerable physical variation and differences in the quality of the several rice varieties cultivated in this country when these run into several hundreds. The etymology of nomenclature in the majority of cases connotes the characteristic shape, size, colour, taste, etc., of grain ; its similarity to other flowers, seeds, and tubers in respect of scent, shape, appearance, etc. ; association with particular places or soils as well as personages ; methods of sowing, etc. All this has given rise to a confusing vocabulary of names to the varieties even in a single tract. It is sometimes puzzling to find over a hundred 'varieties' even in a small tract. Each of these varieties may be taken to be an 'ecotype, a particular reaction system to the environment, a phenotype of variable but on the whole constant expression'. This variety which the farmer recognises is entirely different from that of the systematist.

Copeland [1924] remarks that in rice 'the remarkable number of varieties is associated with the fact that the single kinds thrive only under very narrow limits of conditions to which they are perfectly adapted. It is this fitness of varieties to particular places and uses which explains their perpetuation. But the rice cultivation had gone to an unfortunate extreme in that there are surely countless varieties without which the rice industry would be better off'. The absence of any generally recognised scheme of classification and the need for such a one had led the Rice Congress at Valenica held in 1921 to adopt the following resolution :—

> 'That there may be made in all countries a botanical study of the varieties of cultivated rice, seeking a provisional classification based on characters which may be considered fixed; that when one or other of these characters shall be revised the stations notify those of the other countries busy with studies of this kind for the purposes of attaining uniformity of method'.

From the time the botanist began to work on rice, he did feel the need for a simple botanical classification but was always hampered in his attempts by the difficulty of bringing into its fold all the existing varieties unless he made the classification cumbersome. Bretschneider, Griffith, Roxburgh, Inabu, Tanaka, Koernicke and many more have all been baffled in their attempt to classify rices.

The earliest attempt at classification of South Indian rices, particularly of the Andhra area was by Roxburgh [1832] who based it only on the duration of the crop such as *punasa* (early) and *peddapanta* (late). Watt's [1892] next classification, was confined to agricultural groups in Bengal which took into account the duration as well as the cultural peculiarities of the variety. After him, Graham [1913] made an attempt to classify the rices of the Central Provinces, and he gave prominence to the colour (anthocyanin) in leaf sheath; groups on the basis of leaf sheath were subdivided further on the basis of vegetative characters, those of spikelet and grain, types of facet, etc. The importance of duration was recognised by him. He records that the special rices, such as glutinous, scented, etc., could be fitted in the general scheme or they might be well considered as systematic varieties and kept separate. Beale [1927] has based his classification of the rices of Lower Burma on colour in leaf sheath, stigma and apiculus; he had another physical classification also based on the characters of the grain, size and shape, dividing the varieties into five groups 'A to E' in the descending order of the length/breadth ratio. Each of these groups he further subdivided into early, medium and late maturing classes but generally speaking, there was an increase in the life period from A to E. Several other rice botanists have since dealt with classification of the rices they were dealing with. Among these may be mentioned Thadani and Dutt [1928], Sethi and Sexana [1930], Mitra and Ganguly [1932], Kashiram and Sarvayya [1934], Hector and Sarangapani [1934], Alam [1935] and Kashiram and Ekbote [1936]. The basis of all these classifications is firstly the colour characters of the morphological parts and secondly the size of the grain or kernel. Besides the above, additional characters as for example, awning, arrangement of spikelets in the panicle, size of the glumes, colour of rices have also been utilised in the above classifications. Such additions have only increased the number of groups and made the classification more cumbersome. It is really doubtful if any of these classifications is of practical utility to the plant breeder. The only characters which are of practical use are the life period of the variety and the agricultural season in which it is grown. Next in importance come the grain characters and colour of the kernel. These latter are of special value to the trade and milling industry. It may be useful to quote the opinion of Watt [1892] on classification as it is of importance even today. ' Rice may be grouped by their colour, size, peculiarity of the glumes, etc., but when every effort has been spent, a hundred forms would suffice to break down completely every theory which has been established so that attention would naturally have to be turned to the season of growing, method of cultivation, etc., affording more trustworthy data for classification; the peculiarities of the grain itself might come to aid in the evolution of the classification '.

Outside India the work of Kikkawa [1912] and Copeland [1924] may alone be mentioned. Kikkawa based his classification mainly on the size of the grain and Sethi and Saxena [*loc. cit.*] have adopted this system and added another useful character in their classification, namely, the colour of the kernels. Copeland has suggested a key to classify rices into 12 groups. It is so planned as to exclude at first a number of easily recognized small groups or groups of minor importance and then separate the large groups along the lines of greatest importance or convenience—gluten, habitat, size and shape of grain and presence and absence of awns. This is only a bare skeleton and would include under each group innumerable types quite distinct from each other.

A large number of varieties grown in the Madras Presidency has been collected and grown at the Paddy Breeding Station, Coimbatore, since 1915, which collection at present amounts to over 2000. But the workers there realised that it was very difficult to devise a satisfactory and accurate system of classifying these rices. Owing to the large amount of intergrading of most of the characters, and the variability of the morphological and even colour characters, it was felt that a very broad classification even if possible, was hardly worth the trouble. They never attempted any classification and were content with a description of the types as they believed that it was more easy to identify a variety by eye when one is dealing with them intensively than by reference to key tables. As Watt has said a system has yet to be developed by a study of the structural peculiarities and agricultural manifestations of the several agricultural classes of rice and a judicial combination of these which would enable the rices of all provinces in India to be classified into recognisable groups.

With the growing volume of rice research in India and collection of a large number of varieties in each province and each botanist classifying or describing his types independently, a variety of descriptions had come into being. Such uncoordinated descriptions of types of the same crop plant are bound to lead to confusion and do not help their real object, namely, of giving an intelligible list of plant breeding and genetical material available, so that, others might understand them. Morphological characters on which classification is generally based are only an easy means of distinguishing types but they are not the most important characters. In crop plants especially in India, there exists a close adaptation between local strains and local environment. Two morphologically identical types may not show identity in physiological or agricultural characters. The classification and description of crop plants has to be looked upon as problems in applied genetics rather than those in taxonomy. It was, therefore, felt that the methods of presenting the data should be improved and so arranged as to facilitate comparison of varieties grown in different parts of India. It was considered that such a change could be secured by describing certain characters of the plant rather than the plant itself and that the publication of such records could best be in the shape of standardised tables and schedules. The work of preparing the schedules, charts, etc., was entrusted to a Special Committee with Ramiah as the Convener, and these have since been published for general adoption [Hutchinson and Ramiah, 1938]. To secure uniformity in the description, special colour plates have been included. How the data on the quantitative characters such as yield, number of tillers, etc., which are subject to the influence of environment, should be collected, has also been explained.

CHAPTER V

BOTANY OF RICE PLANT

THE rice plant is botanically a grass included in the great family *Gramineae* to which many of our food grains belong. The exact systematic position of the genus *Oryza* in the great section of *Gramineae* has been dealt with in a previous chapter. It is proposed to describe here a few details of biological interest in the growth and structure of different parts of the rice plant.

Structure of the seed

The fruit of rice which is botanically a caryopsis consists of a loose outer husk, the lemma and palea. The husk varies in thickness in different varieties and also in the case with which it separates from the rice kernel. The structure of the husk is very characteristic and has been recorded by Hector [1937] as follows. 'The cells of the outer epidermis are large, more or less square in outline with thick and strongly developed sinuous walls and arranged in parallel longitudinal rows, and stiff dagger like hairs are abundant. Below the epidermis two or three layers of elongated sclerenchymatous fibres occur. This is succeeded by a mesophyll of rectangular cells with thin wavy walls. The inner epidermis is much compressed and consists of elongated cubical cells with thin straited walls. The testa is a thin practically structureless layer, remnant of the inner integument'. Several other workers, Nagai [1910], Winton [1937], Ramiah and Mudaliar [1937] have studied the anatomy of the pericarp. They have all observed rice pericarp to consist of (1) epidermis, (2) mesocarp or the parenchyma of the pericarp, (3) cross cells (chlorophyll cells), (4) tube cells and (5) spermoderm (inner integument). The endosperm consists of a single layer of polygonal aleurone cells with a central mass of thin walled starchy parenchyma. In the non-glutinous varieties the cells contain numerous small starch granules often compounded into oval aggregates of several hundred grains.

The embryo of rice exhibits no unusual features but possesses in addition to the normal parts, a certain amount of epiblast. Terada [1928] records that on the ventral side of the grain the embryo is 2.19 mm. long and 1.13 mm. broad and is found strongly differentiated, scuttellum, coleoptile, radicle and coleorhiza being clearly distinguishable therein. The plumule, a semi-globular structure growing in the middle, develops into the main panicle in due course. It is reckoned that the primordium consists of three hundred cells in the seed.

Seed germination and seedling

Rice is said to require no dormant period and can germinate at any time after it is completely mature. This may be true of most of the short duration varieties. In a few of these the grains start germinating in the standing crop itself under wet conditions. Tests made in Ceylon, Bengal, Coimbatore and British Guiana point out that while early varieties require no resting period, late varieties require a resting period of three to four months. Experiments conducted at the Rice Research Station, Cuttack, have shown that even in the case of late varieties smoking the seed with cool smoke gathered from cocoanut coir for a couple of hours a day for three days, improved the germination to eighty-eight per cent twenty days after harvest. Dehusking with a wooden mill was found the most effective method of breaking the dormancy [Parija, 1940]. Germination also improved when rice seed was germinated under ultra violet rays. It has also been recorded that soaking the seed in the juice expressed from germinating *mung* seed (*Phaseolus rheus*) diluted with an equal quantity of water gave eighty-five per cent. germination whereas it was only fifteen per cent. in the control.

Interesting results on germination of rice have been reported from studies made at Coimbatore [Ramiah, 1935 and Parthasarathy, 1940]. It was found that the effect of soaking the seed in 0.5 per cent. solutions of potassium chloride, ammonium sulphate, sodium sulphocyanide and manganous sulphate varied with the nature of salts used and light had an influence on the effect produced by these salts. Rice grain germinates immediately after harvest if the bran layer is removed; but the removal of bran layer is not possible after the grain has been stored for some time. While the viability of seed is controlled by the method of storage and the atmospheric conditions acting on it, under ordinary conditions of storage, the viability goes down after some time. There is also a varietal difference in the variability of viability with lapse of time. Even among the varieties harvested at the same condition of ripening, the rapidity of germination may vary. That delayed germination is a varietal characteristic and is probably an inherited one is evident from the observations made at Coimbatore with regard to the germination of progenies of crosses between wild and cultivated rices. While the seeds of wild rice were found to lie dormant in the soil for a very long time the cross progenies took varying periods to germinate.

Pan [1936] records that the varieties belonging to *indica* group, germinated much faster than those belonging to *japonica* group. It was found that seed soaked in two per cent solution of copper sulphate for a short time, dried and stored, kept its viability longer but the rate of germination was slow. An interesting observation made in this case was that the plumule developed first and then the radicle, contrary to what takes place under natural conditions.

Germination of rice is influenced by temperature. The range of temperature over which germination takes place varies from 42°F. to 117°F. and apart from varietal differences, all rices germinate quicker at higher than at lower temperatures. At 108°F. germination is arrested, and beyond 122°F. the seed is killed. The influence of heat also varies according to the nature of grain, whether freshly harvested or stored for sometime. Rice grain can germinate under water because it does not require as much oxygen for germination as other cereals do, and the seedlings can be kept alive for nearly fifty days before they die out. It requires at least twenty seven per cent. of moisture in the soil for germination when the seed is sown in seed beds. After absorption of water the primary root breaks out of the coleorhiza and grows down into soil and very soon two or three secondary roots develop from the node to which the cotyledon is attached. While the roots are developing, the coleoptile and the plumule break through the pericarp and grow upward.

In the young seedling two members are distinguished externally, the cotyledon and the main descending axis. The plumule bud is present but is concealed within the expanded base with or without an appendage formed by the sheath or the coleoptile which protects the plumule during germination. The apex of the hypogeal cotyledon becomes the sucker, scutellum absorbing food from the endosperm. The sucker and sheath are connected by a short stalk. In the small seedling the plumule depends on the seminal root system until it has developed its own roots. The first two leaves draw their water at first from the lower roots through the mesocotyl, which is the fusion of the cotyledonary stalk with the hypocotyl, and they draw the protein from the endosperm through the scutelium.

Roots

The study of the root has not received much attention of the scientists due to the inherent difficulties in separating the roots from the sticky rice soils. The observations made in pots on isolated plants may not represent the actual state of affairs in the field. Sethi [1930] studied the root systems of the varieties in pots and in field. At the end of a fortnight's growth he observed two distinct types of roots; (1) long flaccid, light brown and much branched roots and (2) comparatively short, thicker, unbranched roots of a white waxy appearance. This has been confirmed later by Mukherji [1933].

It has been shown by Sethi [*loc. cit.*] that the rice roots are similar to those of ordinary dry land crops in internal anatomy. This important finding confirmed later by Smits [1931[, governs to a large degree the agricultural practices followed in rice culture. Thus the root development in rice as in other dry land crops depends upon the removal of physical obstacles such as hard pans, improvement of aeration by tillage operations, drainage and manurial applications. Sethi found that the maximum development was found in a clay soil. It was found by Smits that the root development was forced up in drier soil and it was best in full direct light. The depth of root system varied with cultural practices; the broadcast rice develops a deeper but poorly developed root system whereas transplanted rice has a shallow but well developed root system. As rice has a system of roots resembling dry land crops, oxygen has to be furnished only as solution in water that surrounds the roots, and this involves problems of aeration and drainage. The efficiency of green manuring for rice crops is found to lie in promoting the activity of the surface film which is responsible for the aeration of the soil. Application of organic material improves soil texture and consequently root development is promoted. Phosphoric acid among artificials has a stimulating influence on root development.

Sethi found that each of the variety he studied exhibited a characteristic root system. In the short duration types, the root system is less developed than in late varieties. In coarse grained varieties the root system is also coarse in texture compared to the more delicate ones in the fine types. Ramiah [1931] has shown that among varieties of similar duration but differing in height, the downward as well as the lateral spread of the roots is more pronounced in the taller than in shorter varieties. He also found that within a variety there was a high positive correlation between the number of tillers and the number of roots per plant. He later observed [1932] that root development did not stop with the beginning of the flowering phase but continued right up to the end until all the tillers had finished flowering but there was no appreciable increase in length. Certain types of rice known as the floating rices showed poor root systems. Typical swamp or low land varieties developed a more extensive root system under puddled conditions of the soil than when grown under dry or garden land conditions, whereas the typically ' dry ' and ' wild rices ' behaved in the reverse way.

Nodal roots

The typical deep water or floating rices possess another set of roots that develop at the nodes higher up which may be called nodal roots. Like other rices deep water rices also obtain their food supply from the soil but during flood they supplement this by drawing nutrients held in solution in the surrounding water with the help of nodal roots. Nodal roots which are of two kinds, fine and coarse, start at the node just below water level. The development of nodal rooting occurs when water level is stationary and this period synchronises with the time when the demand for food supply is the greatest.

Tillering

When growth commences the hypocotyl remains short, and the lower portion of the epicotyl lengthens into a thin erect rhizome which pushes the terminal bud upwards through the soil. When the primary bud reaches the point just within an inch or so of the soil surface the rhizomatous internode ceases to lengthen and the succeeding internodes of the plumule remain short. The primary axis, however, does not grow very much, but buds are formed at the same time in the axils of its leaves which extend into secondary stems; the latter also bear axillary buds which are capable of developing in a similar fashion into branches of the third order, and so the process is repeated. The production of these numerous shoots with unexpanded internodes which take place near the surface of the soil is known as ' tillering ' and is characteristic of most of the cereals. The depth at which tillering begins is regulated by the light perception of the plant and by the depth at which the grain is sown or the rice seedling is planted. The tillering zone is restricted to half to one inch along the length of the axis and situated within one or two inches below ground level. Sarvayya [1932] found that the tillers were formed on the hypocotyl 1 to 3 cm. below the surface of the soil. When seed was sown right on the surface, tillering was completely arrested.

When the age of seedlings for transplanting is advanced or when the crop lodges, it is usual to see tillers springing up from the higher nodes but these may at best produce very poor ears or in many cases no ears at all. Though not economically important, this secondary branching is connected with the early maturity and ample space for the plant to develop. Certain varieties after they are cut have the power of forming tillers from dormant buds at nodes of the stubble left over, just above and below ground level. Some varieties have a characteristic predisposition, especially the deep water rices, to produce stems at higher nodes which may be rightly called branching rather than tillering [Jones, 1925]. In spite of the very large variation which tillering is subject to under varying environment, it is found to be a varietal characteristic governed by heredity.

Stem

The rice stem or culm is made up of a variable number of internodes, from 10 to 20 depending upon environmental conditions. In the early stages there is not much difference in height between varieties but the elongation of internodes becomes active and continuous later. The elongation is very small in the lower internodes and there is a tendency for the internodal length to increase from the base upwards, the longest internode being the terminal one carrying the inflorescence. The culms are more or less erect, cylindrical and hollow except at the nodes and vary in thickness, and each of these culms normally bears an ear. The internodes of deep water rices are much longer and their elongation depends upon the rise of water level, each internode sometimes reaching a length of even two to three feet. The histology of the stem of the several types of rice in relation to the particular conditions under which they are grown, such as drought, ordinary swamp and continuous submergence will be an interesting study and there is certainly a paucity of information in this direction.

Anatomy of the stem

In transverse section of the stem of the normally growing rice plant Hector [1937] records that the young epidermal cells are somewhat square in outline and later these become much thickened, cuticularized, impregnated with silica to a varying degree. In the interior, the ground parenchyma is at first uniformly thin-walled somewhat angular and closely packed. The cells in contact with the epidermis are first comparatively small but rapidly increase in size later. In the neighbourhood of the stomata they contain chlorophyll. As the stem ages, the cells immediately beneath the epidermis become strongly thickened to form a band of sclerenchyma varying in width in which the outer zone of vascular bundles may be included or may be in contact. In some varieties a narrow band of small-sized cells may border the inner margins of the cavities and are more or less continuous with the sheaths of the inner bundles. Air cavities are always conspicuous in deep water rices. The fibro-vascular bundles of the rice plant show considerable regularity in their distribution. Beyond the outer zone a median zone of bundles often occurs situated at levels between the air cavities. The inner zone consists of fairly large bundles evenly spaced and often forming a distinct ring. Each bundle is of the typical cereal configuration with three large vessels.

Parija [1940] has recorded some anatomical peculiarities in the stem of eleven flood-resistant rice selections. A semilunar sclerenchymatous band which is one to two cells in thickness around the corticular lacunae is observed in most of them and in the more typical ones, the band is supported by an additional cap of sclerenchyma at the lower pole of the peripheral bundles. In Habiganj, Ganguli [1940] found that in some of the deep water rices of Assam there was correlation between the percentage area of air cavities in stem sections and resistance to floods.

Bhide and Bhalerao [1927] and Ramiah and Mudaliar [1934] have studied the stem sections of lodging and non-lodging strains of rice and found that the more resistant types have stems with a thicker band of sclerenchyma at the periphery than lodging strains, more numerous fibro-vascular bundles and exhibits in particular a narrow layer of small sclerenchymatous cells behind the air cavities, more or less linked to the sclerenchymatous sheaths of the bundles which lie between these cavities. This layer is generally absent in strains prone to lodge. Hedayatullah and Chakravarty [1941] made a comparative study of the mechanical system in five species of *Oryza* and found that the wild species were mechanically stronger than the cultivated species.

Blooming and fertilisation

A knowldege of the blooming process of a crop plant is essential to carry out not only hybridisation successfully but to estimate the contamination that might accrue in large scale cultivation of superior varieties. Jones [1929] has summarised the literature available up to 1928 on this subject of blooming and factors governing it with an exhaustive bibliography. In the following paragraphs information is given about conditions in different parts of India (*vide* Table III).

It is generally observed that anthesis commences shortly after the panicle emerges from the enclosing leaf sheath. The sequence of spikelet opening has been studied by several workers. Balajirao [1926] and Parthasarathy [1927] observed that though the course of opening was not regular there was a certain sequence. Generally the blooming commences from the tip of the panicle but does not proceed to the bottom in regular succession. If the position of the spikelets in each branch of a panicle is marked along the abscissae and the order of blooming along the ordinate

TABLE III

Showing hour of blooming, percentage of natural crossing, etc. in rice

Place	Blooming		Temperature at flowering °F.	Percentage of natural crossing	Remarks.
	Month	Time			
India.					
Dacca, Bengal	August	7-00 a.m.	..	4	
Do.	October	9-00 a.m.	..	..	
Chinsurah Bengal	October	9 to 10 a.m.	..	..	
Do.	November	10 to 11 a.m.	..	..	
Bankura Bengal	September	9-00 a.m.	92	..	
Do.	November	11-30 a.m.	83	..	
Coimbatore, Madras	September	5 to 7 a.m.	72*	15—20†	* O. *officinalis* † in O. *sativa* var. *spontanea*
Do.	September	12 to 2 p.m.	90‡	..	‡ O. *longistaminata*
Aduturai, Madras	November	10-00 a.m.	82—84	2—4	
Berhampur, Madras	September	8·00 a.m.	..	..	
Do.	November	10 to 11 a.m.	..	0·5 to 1·0	
Sabour, Bihar	September	7 to 9 a.m.	..		
Do.	October	9 to 11 a.m.	82—97	0·1	
Do.	November	11 to 12 a.m.			
Nagina, United Provinces.	September October	11·00 a.m. 11 a.m. to 1 p.m.	..	2·0	
Raipur Central Provinces.	October	10·00 a.m.	..	0·1—2·9	
Habibganj, Assam	April	8 to 10 a.m.	..	7·9	O. *sativa* var. *spontanea.*
Karjat, Bombay	..	10·00 a.m.	79—84 85—90	0·52	
Larkana, Sind	September	7-30 to 12-30 a.m.	65—84	0·1 to 29	
Java	November	10 to 12 a.m.	..	1·3 to 4 23 rarely	
Phillippines	..	9 to 11 a.m.	..	2·4	
Australia	..	11-30 a.m.	..	4	
Japan	..	9·00 a.m.	95—104	0-4	
Hawaii	..	9 to 10 a.m.	..	*Nil.*	
U. S. A.	..	12 to 2 p.m.	..	0—3·39	

almost similar graphs are obtained revealing a more or less regular order in each branch. Kadam and Patil [1933] state that generally the terminal spikelet blooms first followed by the second; after this blooming goes on from below upwards. The maximum blooming in any plant is attained on the second, third or fourth day under favourable conditions and the whole panicle finishes its blooming in six to seven days.

The opening of the spikelet is dependent to a large extent upon the season and the atmospheric conditions of the day at the time. According to Hector [1913] the *aus* varieties of Bengal commence blooming from 10-00 a.m. and the *amans* from 9.00 and continues until mid-day. Ramiah [1927] observed that one wild species, (*O. officinalis*) bloomed from 5-00 to 7-00 a.m. whereas another species, *O. longistaminata*, bloomed from 12.00 to 2.00 p.m. when the atmospheric temperatures were 72°F. and 90°F. respectively. Whatever the time of the day when blooming occurs, there is only one peak during the twenty four hours when rice plant reaches a maximum blooming activity. Bhide and Bhalerao [*loc. cit.*], however mention that late in October when the days are warmer, blooming occurs in waves during the course of a single day. This is probably more an exception than a rule. Alam and Trivedi [1934] show that the blooming time depends mainly on temperature and humidity prevalent during the period and that it is not so much a function of the variety itself. Further they believe that light is not so important as temperature. Nguchi [1929, a] has studied this question in detail and his findings are briefly stated below.

(1) *Temperature.* A wide range occurs when blooming begins. It is not the direct action of prevailing temperature at flowering time but the action of the morning temperature that is the determining factor in this function. Eighty-four to eighty-eight degrees F. is the most favourable temperature when spikelets open and pollination is effective.

(2) *Moisture and dryness.* Seventy to eighty per cent. humidity is the optimum. Very high moisture content hinders somewhat the opening of spikelets and also the dehiscence of anthers. Dryness with less than 49 per cent of humidity hinders the opening of spikelets. Stigmas are damaged by dryness below 50 per cent humidity. This fact is reflected in the occasional failure of the summer rices setting seed when the weather is very dry and humidity is considerably low.

(3) *Light.* Blooming is irregular in darkness and light accelerates opening of spikelets. Orange light accelerates it most and yellow comes next. Artificial light can also give the same effect.

(4) *Rain.* If spikelets of cereals open during rain, pollination proceeds normally and pollen grains do germinate on the stigma (which is covered with a cuticle and water cannot, therefore, penetrate) but the number of spikelets that open on these days may be small. Both rain and wind may cause spikelet opening mechanically but do not act deleteriously.

The mechanism of opening of the spikelet is still imperfectly understood. Most of the investigators believe that humidity and temperature govern this phenomenon but how these act on the several parts is still not clear. The humidity perhaps causes the lodicules to absorb moisture and swell and these force apart the lemma and palea thus exposing the anthers to sunshine; the filaments are also seen elongating at this time and this may release the hooking of the lemma and palea at the tip of the spikelet. That the lodicules are concerned in the opening is evident from the fact that when the lodicules were puctured the spikelets failed to open, Parthasarathy [*loc. cit.*]. Whatever the cause, the spikelets open more or less at a specified time and the whole process of opening and closing is completed in a short time, the spikelets remaining open only for a short time, 30 to 90 minutes [Hector, 1913].

Under normal conditions, dehiscence of anthers may take place just prior to the opening of the spikelet or at the moment of their emergence from the spikelets or a very short time after they have fully emerged. It may, therefore, be taken that spikelets are, as a rule, self-pollinated. If the optimum humidity required is reached without the requisite temperature, it has been found that the spikelets still open but in this case the anthers do not generally dehisce. This observation has been utilised in artificial hybridisation work as has been shown elsewhere.

Pollen studies

Studies on pollen have been made in Coimbatore, [Srinivasan, 1941]. The size of pollen grains did not vary much within a variety and the contents of the pollen were mostly starch and this streamed out into the tube on germination. Pollen of rice could be successfully preserved for 24 hours at 54°F. with a humidity of 85 per cent. While diastase, pectinase and cellulose were present in the pollen, there was only pectinase in pistil. Pollen germinated on the stigma in about three minutes after pollination, and there was no specialised tissue in the style to induce the growth of pollen tubes. The rate of growth of pollen tube was fairly uniform. The period between pollination and entry of the pollen tube into the embryo was about one hour. Supernumerary pollen tubes are sometimes observed at the micropyle but there is no evidence of polyspermy. Gameto-genesis occurs at least 42 hours before anthesis. The migration of the nuclei into the tube takes place ten minutes after the pollination. There is no appreciable difference in the rate of growth of pollen tubes in the starchy and glutinous varieties. In the cleistogamous rice, the anthers behave normally, but in the absence of ear emergence the spikelets do not open. The pollen in this variety also germinates only on the stigma.

It has not been found possible to germinate rice pollen artificially. Noguchi [*loc. cit.*] has studied the effects of temperature, moisture and light on pollen germination in rice. He found that the best results were obtained when the pollen was allowed to germinate on the stigma. Development of pollen tube took place between 68° to 102°F., and 86°F. was the optimum. Comparison of the effects of saturated, dry and normal air showed that the former two were unfavourable for pollen tube development. Light slightly accelerated pollen germination but did not affect pollen tube growth. He has also recorded that the highest percentage of fertilisation was obtained on the second day after emasculation and pollen seldom lived more than fifty hours. From a study of the period of receptivity of stigma and pollen viability, Ramaswamy [1933] concluded that after the natural opening of the spikelets the stigma maintained a high degree of receptivity for the first three days, started losing it thereafter and lost it completely on the 7th day. Similarly Nagao and Takaro [1938] found that pollination after the first day was the most effective resulting in as much as 90 per cent. fertilisation; on the third day it was 60 per cent. and on the fourth day it was only 9 per cent. The stigma remaining receptive for three days could be utilized in crossing work, either when the parents bloom with an interval of two to three days or when unfavourable weather conditions prevent pollinating the stigma soon after emasculation.

Natural crossing

Since the dehiscence of the anther takes place either just before or immediately after the spikelet opens, self pollination followed by self fertilisation is the result. There is, however, a small but variable amount of natural cross fertilisation occurring in many localities, (Table III). It may be stated that external factors, weather conditions in particular, have a great influence on the extent of natural crossing that may take place in addition to the varietal differences. High humidity and low temperature favour a larger percentage of natural crossing as in Java where up to 20 per cent incidence is reported. Certain varieties like the glutinous types, even very far removed, up to 30 feet, are known to contaminate varieties in the vicinity. It may, however, be mentioned that under conditions where a rice is grown in large blocks natural crossing is negligible and the stock may be maintained free from genetic contamination if ordinary precautions are taken.

Development of embryo

The only study reported on the development of the embryo after fertilisation is by Terada [1928]. He states that the embryo sac develops in a normal way from the lowermost cell of the tetrad, the ovule is anatropus, fertilisation takes place 12 hours after anthesis and that the occurrence of double fertilisation is probable. The antipodals which are at first three in number increase by division, the maximum being less than ten. The primary endosperm nucleus formed by triple fusion undergoes several consecutive divisions before the fertilised egg cell has reached the metaphase of its first division. The endosperm tissue cells are at first filled with a jelly like substance before the appearance of starch grains. About one day after anthesis, a two to five celled embryo is formed.

Ramiah and Mudaliar [1937 and 1939] have studied histologically the development of colours in the seed (kernel) coat and protein in the aleurone layers. Mudaliar [1936] has also investigated the deposition of starch in the rice kernel from the time of fertilisation The results of these investigations are summarised below.

Colour

In rices with dark red kernel, the colour is noticed in the cells of the endosperm on the seventh day after anthesis. The spermoderm cells are uniformly thickened and the deposition of the colours is also uniform. In rices with light red kernel the pigment could be seen only in the inner cutinised walls of the endosperm on the seventh day and extends to the cell cavity on the sixteenth day. In rices with purple kernel the colour is confined only to the cutinised wall on the seventh day. The colour is seen occupying the whole pericarp region by the sixteenth day when the spermoderm is disorganised.

Proteins

Small quantities of protein are present in the wall up to the fifth or sixth day after fertilisation which gradually get exhausted after the development of aleurone and starch cells from the seventh day onwards. The composition of the proteins in aleurone probably changes and it is quite likely that the proteins consist mostly of tryptophane, the most essential constituent of the animal diet. while in the other portions of the grain the proteins are mainly composed of tyrosine. One or two layers of cells of the endosperm adjacent to the aleurone are also rich in proteins. The aleurone on the ventral side of the grain, same side as the embryo, consists of a single layer while on the dorsal side. it is two to three layered. Maximum development of aleurone is observed in the rice with purple kernel while other coloured rices have generally thicker aleurone than white rices. The development of aleurone appears to depend upon the coarseness of grain, the coarser the grain the thicker is the layer (Plate II).

Starch

Starch is noticed on the fourth day after anthesis. In the early stages of the ovary development, starch is present in large quantities in the ovary wall and pericarp layers which get exhausted as the grain develops. In the embryo, starch is formed from the seventh day but by the time the grain is ready for harvest there are only traces of starch in the scutellum.

It may perhaps be useful to record the technique followed at Coimbatore for histological studies of the rice grain. Rice kernels are killed in chromic acid and after thorough washing they are treated with 1 per cent KOH solution for three hours; they are then transformed to 10 per cent glycerine where they remain for five days. From there the grains are transferred through alcohol to a mixture of paraffin wax, xylol and absolute alcohol in the proportion of 1 : 2 : 3. After slow evaporation of the volatile products the grain are imbedded in paraffin and taken to the microtome.

CHAPTER VI

DEVELOPMENTAL STUDIES

THE ultimate object of the plant breeder is to increase the yields of varieties he is dealing with. While agriculturally, yield may be a simple conception as so much of produce per unit area cultivated, biologically, however, yield is a complex, an end result depending upon the genetic constitution of the plant and upon the environment in which it is nurtured. The internal basic physico-chemical characters constituting the vital activities of the plant lead up to the manifestation of external yield characters as growth, tillering, ear size, etc. The necessity for the study of the development of the plant in all its phases needs no emphasis as it is the only direct method of approach to the problem of yield.

The outstanding work regarding the study of the fundamentals underlying yield in cereals,—wheat and barley, is by Engledow and his associates which has added considerably to our knowledge with regard to the influence of the external factors on yield. Of all the morphological and physiological characters, tillering is considered the most important. It has been shown by them that in wheat (1) early formed tillers make larger ears than those arising late; (2) the extent of early tillering is an index to vigour of growth; (3) the average number of ears per plant and average size of the ear increase or decrease together and (4) there is a critical period of tiller formation and all the tillers formed after this period have less chances of surviving and contributing to yield.

The question often arises as to what should be the attributes that must be studied in relation to yield. In the case of the large amount of plant breeding material the breeder is studying, it is obvious that some idea of the comparative development of the progenies should be formed. In deciding upon the particular attributes which are to be measured, the following factors have to be taken into consideration. Firstly, the attributes must be capable of being studied as the crop grows; for cereals the number of plants per unit area, the number of tillers produced per plant, the size and number of ears, date of tillering, length of shoot, etc. come under this category. Secondly, the attribute should be correlated with yield; the influence of environment on this attribute should also be taken into consideration; and lastly, the attribute must be quickly, and easily observable. The frequency of the observation naturally depends upon the character to be measured but it is advisable to fix such periods of observation as would enable the measurements to be taken of all the attributes at the same time. Adequate samples are to be taken and the interpretation of the results of developmental studies are best done by proper statistical analysis.

With regard to rice, developmental studies that have been reported are confined to the tillering phase and generally conducted on single plots [Sarvayya, 1932; Ramiah and Narsimham, 1936]. A large amount of information has, however, been gathered which is detailed below.

Formation of tillers

Tillering starts from below and as the tillers are being formed progressively along the main axis, some of the early tillers start producing secondly tillers in turn. It is found, [Ramiah and Narasimham, *loc. cit.*] that where there is a large amount of tillering, there is some sort of sequence in the formation of secondary and tertiary tillers. The secondary tillers do not produce tertiary tillers unless the total number of tillers per plant exceeds ten or twelve. Tracing the nature of tillering from the beginning, Bhalerao [1926] concludes that it is more of sympodial than of monopodial nature. Ramiah and Narasimham [*loc. cit.*] state that the arrangement of the tillers is alternate in every case, and the course of tiller formation appears to be identical in all the strains studied by them.

Active tillering phase, according to Ramiah and Narasimham is found to commence about two weeks after transplanting and is in full swing for three to five weeks thereafter, depending upon the variety. Apart from the varietal characteristic, abnormal conditions like too much spacing, late planting, excessive nitrogenous manuring, etc. cause the normally dormant buds to get active and produce tillers and prolong the vegetative phase; such prolonged tillering naturally leads to a high percentage of abortive tillers, uneven heading and unsatisfactory harvest. Jacobson [1916] found that a variety that tillers fully no doubt produced a larger amount of grain to the acre than one that does not, but when rice is transplanted, the actual development of tillers can be very largely regulated by a number of factors, spacing being the most important. Fukaki [1927] found that there was maximum tiller production in soil saturated or only slightly submerged under water, insufficient or excessive water reducing tillering. Tillering activity gets reduced also with reduction in the amount of light. Strains which are quicker and earlier in tiller production are generally the higher yielders.

Katayama [1937] has shown that tillering is affected by the length of time the seedlings are kept in the nursery; the longer ages specially with thin sowings produce seedlings too old to tiller at the proper node, the tillering loci being moved upward. In thick sowings and consequent delay in planting tillering is less because of the shorter time available for growth. He also finds that cultural conditions such as direct sowing, spacing, depth of planting have all an effect in altering the tillering loci of the plant, and the optimum stage of planting the seedling is its five-leaf stage.

Critical period of tillering

When the tillering phase has reached its maximum, reduction in tiller number begins generally by death of the late-found tillers. Thus the stage at which enough tillers are formed to result in ears may be called the 'critical period of tillering'. Ramiah and Narasimham find that this period is reached somewhat earlier than the period of maximum production of tillers. Grant and Aung [1941], however, state that there is no definite critical period of tillering under Lower Burma conditions, the period of maximum production being attained 30 to 40 days after transplanting under normal conditions which, however, gets extended with wider spacing. Studying a large number of rice varieties Chakravarty [1938] finds that in Bengal the rate of tiller production is very active in the fifth and sixth week after planting, and he recommends that as little standing water as possible should be kept in the field until the fourth week followed later by a plentiful supply of water, and this, according to him, results in a large number of productive tillers. All workers are, however, agreed that early production of tillers is associated with a large number of final productive tillers per plant on which yield depends. It is, therefore, important that all agronomic practices should be such as to give the plant favourable conditions for vigorous growth in the early stages. In all probability the primary stem of rice under transplanted conditions acts as a host for the subsidiary daughter tillers for sometime only and as the late-formed tillers do not develop any root system to lead an independent existence they naturally die. Inpsite of different number of total tillers produced in the several varieties, the percentage of reduction in the number of tillers is almost similar in the varieties studied by Ramiah and Narasimham.

Tiller production and yield

In wheat the increase in tillering is associated with greater yield, greater tiller production is a sign of greater vigour as is evident from the fact that yield per ear gradually increases as the number of tillers per plant increases. But in rice, it is not the total production of tillers that is important but the number of functional tillers and it is found generally that the greater the number of productive tillers the greater is the yield. As regards weight of grain per ear there was not much difference between plants with different number of ears in the same variety [Ramiah and Narasimham, *loc. cit.*] which results are in variance with those of wheat. In one or two varieties, however, for example, Geb. 24, they find that the yield per tiller increases though slightly with the increase in number of tillers per plant. Such varieties are very useful in that there is an association between greater tillering and greater vigour, a great desideratum in strains. It is essential to clearly understand as Jacobson [*loc. cit.*] points out that tillering, number of grains per panicle, etc. are elastic and compensating characters. Each in turn is affected by the one preceding it and the development of the character is extended or curtailed by the prevalent environmental conditions and is based upon the extent of development of the preceding character.

Ramiah and Narasimham [*loc. cit.*] determined what contribution each of the tillers makes to the total yield of the plant. Seedlings with three tillers in tact and with each of the main, second and third tillers removed, were planted in an experiment and studied. The results showed that the total number of functional tillers produced and also the yield per plant were higher with all the tillers in tact; while the removal of either the second or the third tiller or both did not reduce the yield obtained, the removal of the main tiller not only resulted in less yield but also delayed flowering. The results definitely indicated the advantage of the lead of the main tiller in point of age and development towards contribution to total tiller production, total yield and earliness in flowering.

Shoot growth

A rice plant during the process of tillering and until the formation of the primordial ear does not show any elongated internodes, the exception being the deep water rices. Vigorous shoot growth starts only with the commencement of ear formation. If a shoot has, say, five internodes, the basal one starts its growth first, quickly followed by the one next above it. The next two commence their growth a week after and almost complete it by the time the topmost one and the peduncle begin to grow. The ear completes its growth in length a week to ten days before its emergence. The height of an individual tiller appears to depend entirely upon its vigour and environment than on its chronology; in spite of initial differences, late formed tillers speed up and attain the same height as the first formed ones. Generally the heights of different tillers of a plant of normal growth are almost the same, the differences being within ten per cent. of the mean. In Pusa, Krishnamurty [1937] has studied the growth of four types of rice and the results have, in the main, confirmed the observations of Ramiah and Narasimham. Adair [1936] observed that increase in plant height was relatively rapid the first six weeks after seeding, then it was slow for about two weeks followed by a rapid increase again until blooming time. In his studies he found that little significance could be attached to the values of the exponential equation which governed growth in many organisms.

A plant takes five to seven days to complete the emergence of all its ears whether it is a good, average or poor tillerer; the forwardness in emergence as in the case of height depends upon the vigour of individual tillers and prevailing environmental conditions. The modal date of emergence of the ear is slightly earlier in a well-tillered plant than in one with fewer tillers. The number of leaves formed above the prophyll or tillering zone of the main and side tillers is a fairly constant character for the variety. The range is found to vary from five to eight leaves per tiller in different varieties

Ear development

Unlike in other cereals in rice there is some interval between the completion of tillering and the commencement of ear formation. This interval increases with the duration of the variety. In very early varieties the ear is formed even before the tillering phase is completed. The formation of the ear primordia commences, 24 to 30 days before the date of emergence of the eartip, the interval obviously depending upon the duration of the variety in question. The development of inflorescence was studied by Terada [1928] from the time the seed was sown and he found it was 0.35 to 0.4 mm. in length 90 to 100 days after sowing and then it began to develop quickly. The relationship between tillering and ear formation is a useful criterion to adjust the time of applying fertilisers. All manuring, it would appear, should be done a month or 40 days before the ear tip emerges.

Sequence of flower anthesis and weight of resultant seed

An interesting experiment conducted by Ramiah [1936] related to the weight of seed formed in relation to the day of anthesis of the spikelets from which the seed resulted. A plant with five tillers was selected and the spikelets that flowered on particular days in it were marked, and the seed formed from spikelets blooming on the same day were gathered and mean weight of individual seed obtained. The date of anthesis and the weight of individual seed gave a correlation coefficient 'r' = 0.45 ± 0.03 showing that gains from spikelets that bloom late are smaller in size.

CHAPTER VII

BREEDING TECHNIQUE

THIS chapter deals with an outline concerning the raising of the crop, conduct of tests with breeding material, technique by hybridisation, etc. Most of the information given is based upon the experience gained at the Paddy Breeding Station, Coimbatore, but wherever additional information was obtainable from other sources it has been incorporated.

Growing material for selection

After obtaining samples of a particular variety on which intensive progeny selection work is to be undertaken they are grown on the station in lines in a uniform field of average fertility. Excessive manuring or intensive cultural methods may not be practised on the breeding plot as it is only then that the potentialities of the individual plants are more clearly brought out. Growing these samples on the station may preferably be done on a replicated basis. It is essential to transplant plants singly with the spacing which is usual in the locality. On the basis of duration, height, tillering, general uniformity of the tillers, heaviness of head and other characters which have a relation to yield, plants may be selected taking each plot in each block as a unit.

Laboratory examination

Whether the selections are made in the cultivator's field or from samples grown on the station, they may be subject to a preliminary examination in the laboratory to eliminate undesirable ones from the examination of the panicle, size of grain, colour and consistency of kernels, amount of sterility, etc., and obviously bad selections may be eliminated. The cultures which are retained are labelled in a systematic manner and the seed stored in glass bottles or paper covers with a small bit of napthalene.

Study plot

Nursery. Depending upon the system of raising seed beds in the locality whether dry or wet, seed beds are prepared and seed of each selection is sown separately fairly uniformly in small seed beds. Delay in sowing of the seed or in the transplanting of seedlings results in an unsatisfactory crop and the inherent characteristics of individual plants may not be brought out well. The seed bed life is generally about a third or a fourth of the total life period of a variety, and hence it merits also a due share of attention and study. The initial vigour of the seedlings, the tendency to tiller, susceptibility to attacks of diseases and pests in the nursery are all points which may be taken note of. Whether the transplant field is manured or not, cultivators generally manure their nurseries, and so the selections may be raised in normally fertile fields. When nurseries are to be raised dry as in the purely monsoon dependent areas, they are to be sown as early and in as short a period as possible taking advantage of the prevailing weather conditions.

Transplanting. Of all the operations in rice culture, that of transplanting is most important and one in which mistakes can happen easily, it requires constant supervision of trained staff. As the operation is carried out in puddled fields with one or two inches of standing water there is first the

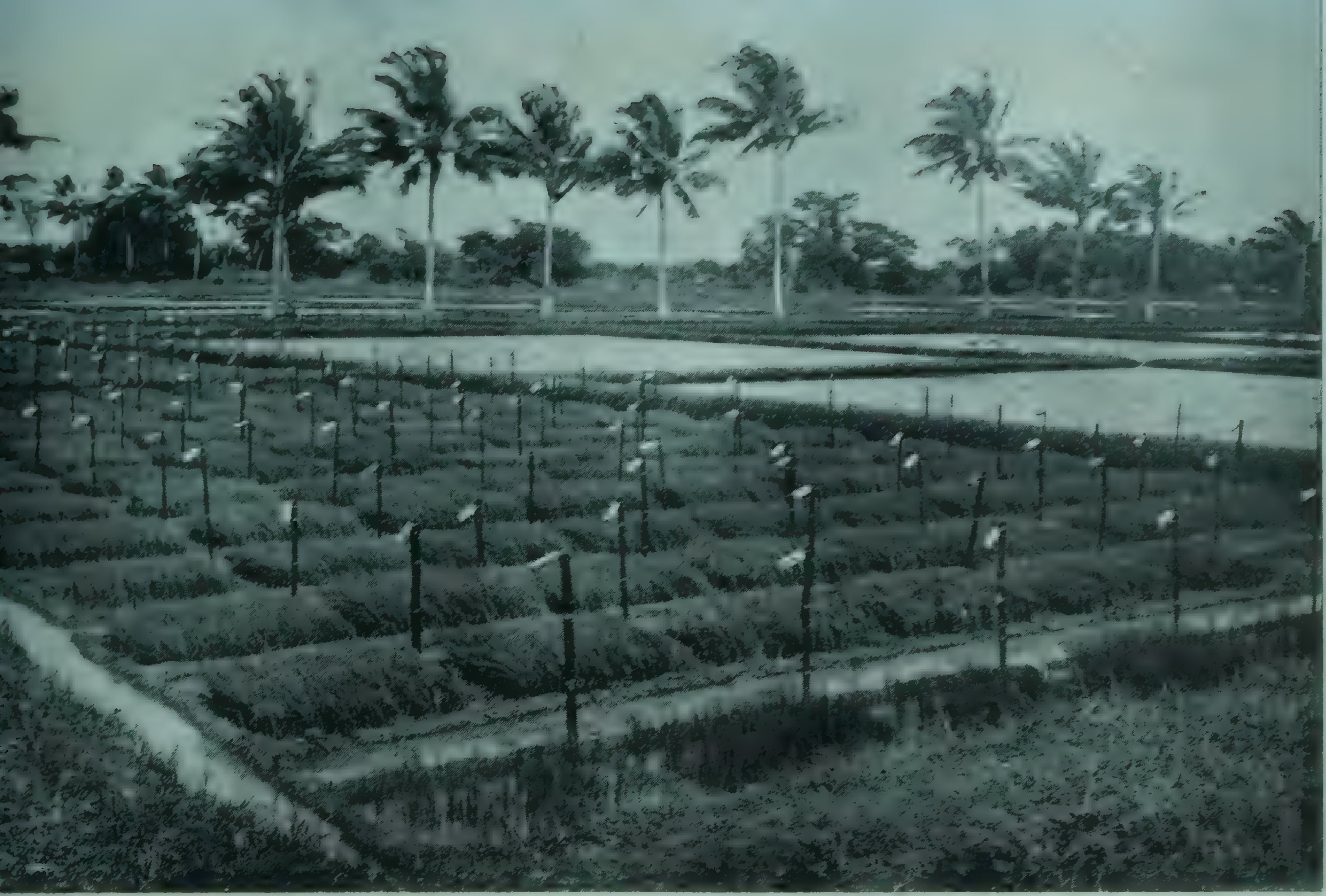


FIG. 1 Seed bed for single plant selections

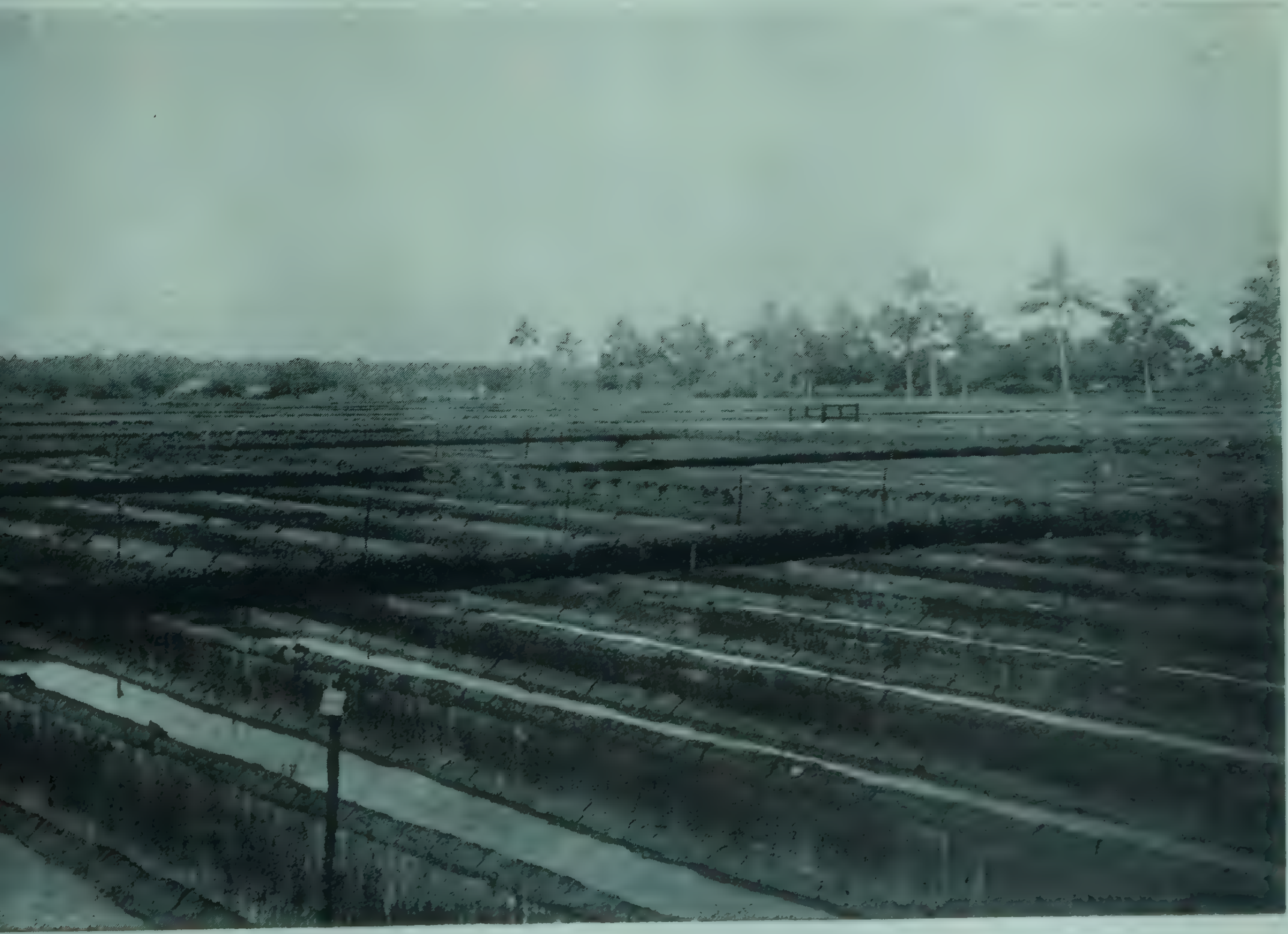


FIG. 2 Seed bed for bulks under yield trials

PLATE

Transplanting comparative trial plots

difficulty of marking out equal strips of plots for planting. Generally the strips are marked off by a pair of thin coir ropes with the required width between them. It is usual to leave a small border all round the field near the bunds. This border can, however, be planted with some non-experimental material. The planting of the seedlings at equal distances is secured by a pair of straight graduated sticks on either side close to the strings and another graduated stick in the centre.

Rejection of inferior progenies

A vulnerable point in the selection work is the way in which poor cultures are eliminated and desirable ones retained. In earlier years there was no criterion to make this part of the breeder's work rational and definite. He had to fall back upon his experience and judgment. The advance of statistics has, however, come to his rescue and it is now possible to eliminate a good portion of the disturbing elements of environment and put his technique on a rational basis. These improvements in technique do not, however, dispense with the personal equipment of the breeder which still counts a lot for the success of the undertaking. Continuous observation of the crop in the field is indispensable and is of great help in utilising the statistical data intelligently.

When the number of selections has been brought down to manageable limits, it will be worth while to test the purity of the selections side by side with undertaking yield trials. At Coimbatore it has been found that observations on three quantitative characters namely, flowering duration, height of plants and size of grain give very useful criterion whether any particular selection is worth carrying forward or not.

FIELD TECHNIQUE

Progeny row breeding

When a breeder is dealing with a large amount of single plant material selected either from natural populations or from crosses it is desirable he should be able to form an idea of the potentialities of his material stripped off from environmental influences at as early a stage as possible. The small amount of seed in the initial stages and the presence of heterozygosity in the hybrid progenies are sometimes considered as difficulties against conducting randomized and replicated trials. But these are not real difficulties. In transplanted rice where it is feasible to obtain a very uniform crop, small plot size does not show unreasonably high error variances. The second point that in the early stages the genetic variances in the heterozygous material contribute to the error variance is a real difficulty but, where there are no great differences in the variability between progenies there is no risk of drawing erroneous conclusions. On the other hand, as the estimation of genetic variance is of first importance to the plant breeder, the technique of replicated randomization is of value both for the homozygous and heterozygous material.

The design of field test for breeding material has been worked out rather fully at Indore, India [Hutchinson and Panse, 1937] and also abroad for a variety of crops. The essential features of replicated progeny row technique are : (i) Increased accuracy and greater objectives, i.e., freedom from personal bias and the comparisons resulting in a much greater efficiency.

(ii) What is even more important, the material is subjected to a steady sifting process and the method forms a measurement of the capacity of plant breeding material to respond to further selection as well as of evaluating the effects of previous selection.

By reducing the size of the plot suitably it is possible to include even as many as 100 cultures in a single randomised experiment. If the number of families and progenies is very large, a good deal of computation labour is involved but this can be minimised by judicious selection made on family comparisons before progeny analysis are taken up. In many cases a thorough field examination even in the early stages will help in discarding all progenies of inferior families which may all be harvested together.

As early as 1915, Parnell, who was the first in India to introduce the error concept in field experiments, had examined a large volume of data on experiments in rice then available and recommended long and narrow plots as more suitable from the point of view of operational convenience and probably also from an analogy of results in other crops where long narrow plots were found to sample soil variation better. Since then a large number of uniformity trials has been conducted for determining the optimum size and shape of the plots for field experiments. The broad conclusions that may be drawn from these studies are (i) the observed frequency distribution of yield from plot size of one-thousandth acre is mostly normal ; (ii) there is some reduction in error when plots are laid with their length lying along the fertility gradient and by compounding blocks at right angles to it ; (iii) there is no gain in precision in the use of long narrow plots instead of plots square or nearly square ; (iv) the smallest residual variance occurs with plots of fairly large size, one to two cents in area, but taking into account the possible increase in the number of replications, the net residual variance is lowest in plots as small as 5 ft. × 5 ft. ; and (v) the differences in the comparative efficiency with plot sizes of 5 ft. × 5 ft., 5 ft. × 30 ft. and 15 ft. × 30 ft. are small which makes the range of choice fairly wide.

Preliminary yield tests

The cultures which have been selected from the study plots may then be compared including the standard variety from which the cultures were originally selected, keeping the size of the plot to at least 100 sq. feet in the case of transplanted rice and about double the size in the case of broadcast rice. A word or two may be said about the standard variety to be used as control. A portion of the original samples which were collected may be kept on at the station itself without any selection being made in them, and if time permitted, a comparison of their yields may be made in a randomised block trial and the best of the samples may be included along with the cultures to be compared. As an alternative, a composite bulk containing equal quantities of these samples may be made and used as control.

Suitable notes with regard to stand, early vigour, height of plant, tillering, etc., may be made at different stages of the crop. Rejecting one row of plots all round to avoid any discrepancies with regard to the intervarietal and border competition, the cultures are harvested, threshed, and weighed separately until constant. For practical purposes, it would appear that two days' drying is enough to reduce the grain to approximately the same percentage of moisture content. From a statistical computation of yields sometimes of both grain and straw where the latter is also important in a tract, the best of the cultures are retained for field scale tests.

Field scale tests

Replications to give a minimum of 15 degrees of freedom for error are found enough for simple experiments. If field space permits, the size of plot, and the number of replications may be increased. It is recommended to plant the strips with the usual spacing obtaining in the locality and under ordinary cultural conditions. From an examination of the yield data and other desirable characters for two or three years, it may be possible to reduce the number to the best two or three. If these cultures are found to possess some distinctive features of their own in addition to good yield, it may be possible to retain them as separate strains and to distribute them to cultivators. But the tendency for many investigators in India has been to multiply a large number of strains without sufficient justification for the same. It may happen that these cultures may be more or less similar, in which case, it may be advantageous to gather more information about the range of their adaptability, so that it may be possible to find out the most cosmopolitan of these. Complex experiments for this purpose—such as the split-plot design or confounded designs may be used. Two or three levels of manuring, two or three spacings may be included and the most cosmopolitan of these for all conditions may be ultimately decided upon.

District trials

It has been felt by all crop breeds that a strain good at one place need not be so at another, especially in rice where environmental conditions influence the yield very much. It is a wise policy to supplement the trials at the research station by actual field scale tests in cultivators' fields. If facilities for supervision and conduct of field trials are available, replicated randomised block trials may be arranged in the tract in as many centres as possible, all with the same plot size and number of replications. These trials would reveal the suitability of individual strains to individual tracts thus enabling to delimit the area for particular strains. Recently it has been shown that the trials to be conducted on cultivators' fields can be very much simplified. Each cultivator without having to run a regular replicated trial may grow only a pair of blocks in one village, and as many villages as possible may be included in these multiple trials. With a pair of blocks in each village, the data provide additional information regarding the significance of interaction between strains and places; the trial may even be divided into single blocks entrusted to one cultivator, (randomisation being made separately for each block) and an analysis of variance made taking each cultivator's set of plots as one block. If these trials are run for two or three seasons in the same place with the same design and, if the variance of individual trials in a set are not significantly different these results can be combined. Such a combined analysis will give a good deal of information with regard to the suitability or otherwise of a strain over a wide area. Where the variances of the individual trials are significantly different, Yates and Cochran [1938] have suggested appropriate methods of combining the results and draw much useful information particularly when the number of trials is large.

In rice, yield must remain the most important of all considerations for a long time to come. Thus in choosing between two rice strains, the higher yielding one should be preferred. But when the number of strains is reduced to a workable limit, such characters as resistance to lodging, shattering of grain, volume—weight, milling or husking quality, cooking quality (*vide* Appendix IV) are also taken into consideration and these form a basis for deciding the strains to be finally released. One important requisite is to see that the strain which is intended to replace the common variety is not radically different from the latter as otherwise the cultivator may refuse to accept it and thus the whole work may be rendered fruitless. It is also useful to obtain and give due weight to the opinion of trade on the strains before they are actually released.

Sampling

The whole theory of statistical induction has been developed on the assumption that a given statistical measure of a sample may be taken to apply to a larger group than that from which it was actually derived. In the study of characters ancillary to yield or taking observations in several varieties it is obviously necessary to limit the observations to a part of the large number of plants composing each variety. In some cases as in yield trials laid in remote places in the tract lacking facilities of separate harvests and accurate weighments of each of the entire experimental units, it may be necessary to restrict the actual yield test to samples from the main plots. Sampling should be adequate and random.

Scattering of sampling units may be done in a variety of ways. In plots consisting of say, 10 rows, it may be decided that 30 ft. lengths are to be taken from each plot, they may be placed entirely at random, three foot lengths for each row or each row may be divided into three parts and one foot in each of the portion may be taken by draws. If the area is a block planted without regular rows, it may be divided into many sections and sampling units taken from each section.

No extensive sampling studies involving estimates of sampling errors have been reported in rice. Kadam *et al.* [*loc. cit.*] have found that three sampling units of 3 ft. × 3 ft. for a plot size of 33 ft. × 33 ft. furnished 92 per cent. of the total information with regard to yield in rice. A large amount of data on sampling for different characters in replicated experiments have been gathered in Madras and their analysis should provide valuable information.

HYBRIDISATION

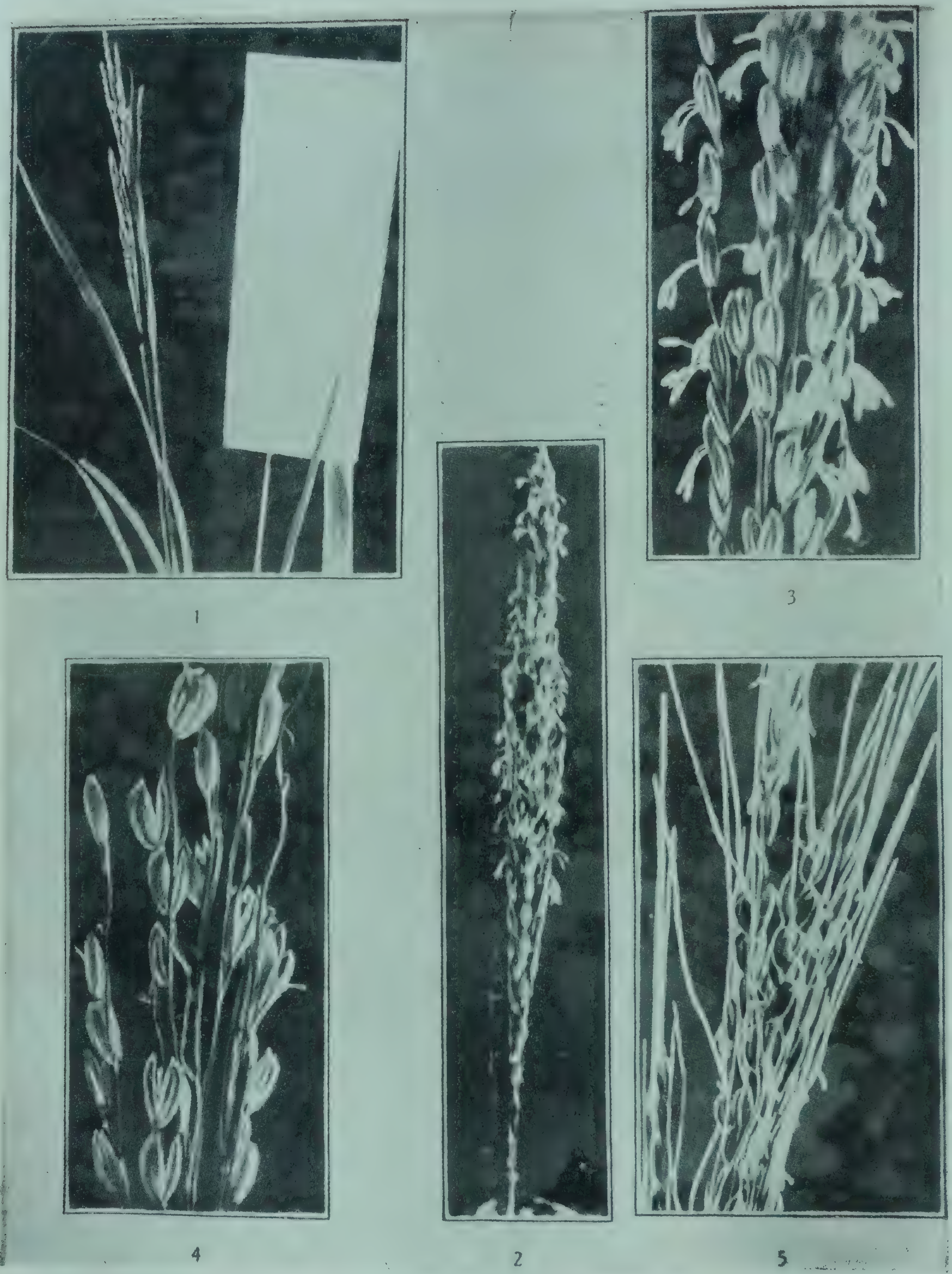
Technique

Rice Botanists in India and elsewhere have evolved their own crossing technique. Some find it convenient to grow the plants in pots and keep them near the laboratory, while others manipulate on plants growing in the fields. The methods of emasculation adopted in different places are described below.

The method adopted in Bengal [Sharangapani, 1924] consists in gently pulling apart the lemma and palea an hour or two before natural opening, removeing the anthers and tying the spikelet with a silken thread after pollination. Bhide [1925[recommends removal of the anthers as and when the spikelets open naturally but this cannot be satisfactory as a good

PLATE V

Harvesting comparative trial plots



Method of artificial crossing in rice

1. Paper cover in position over one panicle
2. Same panicle after removal of cover
3. Portion of same panicle to show free emergence of anthers
4. Spikelets after emasculation. Unopened spikelets removed
5. Portion of panicle of awned variety, showing emergence of anthers

percentages of selfed seed results. Poggendorff [1933] follows Bhide's method. A simple method devised by Ramiah [1927, a] is described below (Plate VI). A panicle preferably one that has started blooming the previous day, is selected in the female parent and after removing spikelets already fertilised, the panicle is enclosed in an ordinary dark brown paper envelope, both the envelope and the panicle being held in position by a bamboo stake into the mud by the side of the plant. The enclosing may be done an hour or an hour-and-a-half before the probable time of natural opening. The cover is removed after about 10 or 15 minutes depending upon the sharpness of the sun when it is found that all the spikelets which are to open that day have opened in a flush with the undehisced anthers hanging out. The anthers are removed at once and pollination can be done when the pollen parent is ready. The spikelets do close again by the time pollen is ready but opening them artificially in this case is much easier. This method of crossing has been found to give nearly 90 per cent. success under Coimbatore conditions and is also time saving. This technique has since been found successful at other centres also. Where a large number of crossed seed is desired for special studies, this method is particularly useful. After pollination, the rest of the unopened spikelets are cut away and the panicle is covered with a muslin bag which is removed after two to three days. It is desirable to allow the pollinated spikelets to develop in the open as it has been observed that inside the bag the seeds do not generally attain their full development.

Torres [1930] suggests cutting the top of the lemma and palea and removing the anthers through the opening. The emasculation is done in the evening and the stigma pollinated the next morning. This method gave only a small percentage of success when tried in Coimbatore, but Mulimbayan [1935] finds that this method was more suitable both for long and short grains than forcing open the lemma and palea. Jordon [1938] compared three methods of emasculation, the 'clipping method', the 'split method', and 'hot water treatment', the last consisting in immersing the panicles in hot water at 40°-44°C. in thermos bottles for 10 minutes and then withdrawing them into the open. By this method not only the spikelets open naturally but also the viability of pollen is destroyed. Temperature higher than 44°C. is harmful to all the tissues.

When varieties to be used as parents differ in their life periods, the plants may not be ready for crossing at the same time. The difficulty can be overcome in the following manner. (1) The long duration variety is sown somewhat in advance of the short one or the short one is sown late. (2) The tillers of the late variety are cut back six inches above the ground level when new shoots appear ; the stage at which the cutting is done is suitably adjusted to get the blooming of the two to synchronise. (3) The late plant can be subjected to short days by cutting out light. It is possible to make the plants bloom 40 to 45 days earlier by this last method.

The cross seeds may be gathered a month after the hybridising operation, dried and preserved in an air-tight sample tube. The failure of cross seeds to germinate which occurs sometimes is more often due to harvesting the seed when not sufficiently mature or to later defective drying and storing.

Raising F_1s and F_2s

As the cross seeds are valuable, they are generally first sown in small seed pans and transplanted in the field, when the seedlings are a fortnight to

20 days old. Since the seedlings will be delicate at this stage they will have to be well protected. They may be put on a small mound and retransplanted again after they have become sufficiently strong. It is usual to give the F_1s wide spacing to secure a larger amount of seed for F_2 growing. To avoid any natural crossing it is safer to self a few plants in the F_1 stage. For selfing, a muslin cloth bag with a triangular base may be used to cover the whole plant, the mouth of the bag being secured at three places to stakes stuck in the mud. It has to be mentioned in this connection that the setting of seed inside a cloth bag is never normal. There is always a certain amount of spikelet sterility in selfed plants. Selfing is particularly necessary in genetical work.

It will be a useful plan to grow a few lines of the two parents at every stage along with the cross progenies for a ready comparison of the several characters. If a large number of cross seed is available it may even be advantageous to transplant the seedlings with the parents in randomised and replicated blocks. If a number of crosses with the same object between different sets of parents is available, the split plot design may be used, each F_1 with the parents forming the main plot treatment. This arrangement would give us an idea of the comparative genetic variability between the several crosses and may give an insight as to which of the crosses may be intensively studied later. The ordinary routine observations which are involved in selection work which have been outlined previously are also applicable here but in addition, observations are to be taken with regard to the segregation of the several characters. In rice where the anthocyanin colour characters in the several parts are quite variable, observations may be necessary at different stages of the crop. The F_2s and F_3s are also preferably laid in replicated progeny rows. It generally happens that when dealing with quantitative characters such as yield, tillering, etc., it is found that after continuing the study for several generations the desired combinations are not realised. This is obviously due to some genetic correlations which have not been discovered in the early stages; it is, therefore, important to study the F_2 in as thorough a manner as possible from all angles including scoring of the quantitative characters and examining the different correlations that may exist between characters. If the desired combinations of economic characters are not present in the F_{2s}, it is no use pursuing the study further for these ends. It is generally better to grow a larger number of F_3 progenies limiting their size than a few but larger F_3s.

PART II—BREEDING OF RICE IN INDIA

CHAPTER VIII

APPLICATION OF GENETICS TO THE IMPROVEMENT OF RICE

THE ultimate object of all plant breeding programmes is to produce plants with useful characteristics and the methods of genetics become therefore useful only in so far as these characteristics are heritable. Many of the characteristics which are useful to the grower are influenced largely by environment, and thus methods of husbandry and methods of genetics appear to be interdependent. It is generally pointed out that the influence of genetics on plant breeding has been much less than what was expected by the earlier investigators. Still the number of achievements in the realm of plant breeding is fairly large, and these results have been achieved by practices which were essentially in accord with the principles of heredity though the knowledge about these principles came in later. The discovery of the laws of heredity by Gregor Mendel and the later developments in genetics and allied sciences have rendered a great service to the breeder. In fact, it is these developments that are responsible for raising plant breeding to the rank of a science. The masterly idea of Johannsen's pure lines has made selection work more stable and saved many fruitless attempts from being launched. Post Mendelian laws, the law of the number of linkage groups and the law of linear relationship in the arrangement of genes, both of which were brought to light by the achievement of Morgan and his associates have added greatly to the knowledge about Heredity and Variation. The developing science of cytogenetics has cleared many obscure situations with regard to sterility, taxonomic relationship between the species of a genus and between different genera, etc. The study of quantitative characters involving the new conceptions of multiple factors, physiological and genetic correlations, is intimately associated with a sound knowledge of applied mathematics; this study has made rapid strides in recent times, and the principles are beginning to be applied to practical breeding programmes. Artificial modifications of genes by X-ray, chemicals, etc., thereby inducing alteration of characters, are being undertaken. The modern development of vernalisation, species crosses, etc., sponsored by the Russian scientists have considerably altered the outlook of the plant breeder.

In India, scientific plant breeding which is not more than 30 years old is being carried on along the traditional lines of introduction, selection and hybridisation which in fact were the ones that were being followed in other countries too. The results of these methods in rice may be gauged from a reference to the large number of useful strains that have been evolved in the several provinces. These improved forms are found to give at least a ten per cent higher yield than the local varieties, and are in some cases better in quality and resistant to some fungal diseases. The area under improved strains evolved by the Departments of Agriculture has, however, not increased to any great extent. The reasons for this situation are to be sought elsewhere and not to the non-appreciation of the value of improved varieties by the rice cultivators.

With regard to the study of genetics of the rice crop in India and its influence upon breeding programmes, it may be mentioned that it may not compare with the results achieved in other cereals cultivated in the Western countries such as maize or wheat. One of the reasons for this state of affairs is that, while such studies in other countries are undertaken by private bodies such as Universities and Special Institutions, in India, the study of genetics has been mainly the concern of the Provincial Government Departments of Agriculture and as such limited by the practical bearing which it has on the plant breeder's programme of work. The methods followed in rice in the light of developments in genetics may now be examined.

INTRODUCTION

It has been found from experience that indiscriminate introduction of a variety from one country to another or from one tract to another within a country is not successful. The good performance of a particular variety in an area means that the genetic makeup of that variety reacts favourably to the environment in that area. When the environment is changed, the reaction of the makeup also changes which results in poor performance. There have been several instances of varieties introduced from foreign countries having failed in India. None of the varieties of rice introduced from sub-tropical regions as Japan, Korea, Italy and America has been of use except as parents in crosses. Similarly there are also several instances of improved varieties proving a failure when introduced from one province into another in India. As an example of successful introduction of foreign rices in India may be mentioned the case of some Chinese varieties which have done quite well in Kashmir and in some of the other provinces. More than soil differences it is the climate, particularly the length of day, and temperature which are different in the sub-tropical and tropical countries that have been responsible for the failures. There is also another point to be remembered in the case of introductions. Very often the variety to be introduced is a stabilized one in its home, i.e., the genetic variability is at its minimum. As such it does not offer much scope for making selections suitable to the place to which it has been introduced. It is sometimes stated that the introduced variety will gradually acclimatise itself to the new set of conditions and may improve its performance in course of time. This is hardly to be expected in material where there is not much of genetic variability left. While it may be necessary to have a live collection of as many forms as possible on research stations, there should not be any difficulty to decide soon which of the material will be of use for direct cultivation in the new place. Before introducing any variety, the breeder should examine the seasonal and climatic conditions obtaining in the tract in which it is grown and also get a clear picture of the history and behaviour of the variety. This will avoid much disappointment and waste of effort.

SELECTION

The varieties that are grown by the cultivators especially in the countries where plant breeding methods have not been practised for crop improvement are found generally to be a mixture of a large number of genotypes. Even those plants which are phenotypically alike, may comprise of genotypes with varying economic, physiological and other traits. Plant breeding essentially is the exploiting of the variability present by selecting, testing and sifting of the material available. Selection methods may be broadly grouped into (a) mass selection, (b) selection from natural populations and (c) selection from progenies of a deliberate cross.

Mass selection

Mass selection is the crudest and easiest form of plant breeding, and consists of selecting good individuals all alike and breeding them *en masse* irrespective of their genotypic value. It is based upon the phenotypical values of the plant and success is entirely dependent upon the phenotypic characters being an actual expression of genotypic constitution. Rimpau's method of sowing the grain under ordinary conditions with a minimum amount of fertiliser upon land and then making selections has shown that the best individuals show themselves very well as the variability due to environment is greatly reduced and genetic variability is allowed full play. In trials conducted in the Philippines with regard to mass selection methods, it was found that seed, mass selected from rice fields having several plants to the hill did not always give increased yield; but seed mass selected from a field with a single plant to the hill gave increased yields. This was due to the fact that all plants in the hill had to be taken as it was not possible to separate the individual plants, hence good and poor genotypes got included. It may be mentioned that the method of mass selection was in vogue in Italy and Spain not very long ago.

Single plant selection

Plant as a unit. The scope for improvement by mass selection can however, be only limited and temporary in nature and has to be repeated every year. In contrast to this when the basis of selection is a single plant, its genotypical value becomes apparent by the behaviour of its progeny, and the improvement achieved is of a permanent nature. All modern plant breeding work consists in selecting individual plants and judging their merits by the performance of their progenies. When selecting desirable plants it must be remembered that the characters of the whole plant are more important than those of any particular part; the more uniform the plant is in all its parts the greater is the likelihood they will prove better for selection.

Characters given weight to in selection. In India paramount importance has, for a long time to come, to be attached to yield, all other considerations being only secondary. We can, however, approach yield only from an integration of its visible attributes. Thus a knowledge of the attributes on which the superiority of the variety depends, is an essential requisite for successful plant breeding. This would entail study of the attributes in data collected from replicated experiments.

Though tillering is considerably subject to environmental influence, studies at Coimbatore have shown that it is a varietal character. Even amongst the strains of a variety it is possible to distinguish a good tillerer from a poor one. In crosses between poor and good tillering varieties studied at Coimbatore, the coefficient of correlation between F_2 and F_3 means was +0.6 in one cross and +0.2 in another. This would indicate that there was a large number of genes in play in the latter than in the former. Selection for better tillering should give results more quickly in the former than in the latter. The partial correlation analysis by Narasingarao [1937] has shown that the number of tillers per plant has the greatest relationship to yield and then comes the number of grains per ear.

There are also certain other considerations which breeders have found useful to remember while making selections. For example, in a given variety the rice plants with a slightly spreading habit of tillering have been found to give more satisfactory yields than those with a typical compact habit. Similarly, when there is variation in the depth of green colour in the foliage, selections with light green foliage have always proved better than those with dark green foliage. The heaviness of the earhead is always a useful criterion to go by in making selections. It will be a waste of effort to try to combine high tillering with greater ear size as there is a negative physiological correlation between these characters. Strains of outstanding value are found to possess a relatively small head while many inferior strains are characterised by strikingly large ones. Hector [1922] has shown that pure lines started from tillers with a high and low number of grains respectively have bred true in many cases. 'An instance of this would be the capacity of the grains from the main tiller to produce more with a higher average number of grains per tiller than the progeny from the side tillers of the same plant'. But work elsewhere in India and in Java has shown that it is ineffective to select principle culms to increase yields. Jack [1923], has also reported from Malaya that yield has no relation to the position of the seed on the head. Thompstone's work [1915] in Burma showed that by taking the weight of a definite number of seeds in addition to the total weight of grain per plant, a good idea could be obtained of the merits of a pure line at an earlier stage than might be done after testing it in the field. McKerral [1913] has suggested that the grain-straw ratio was an important character which had to be better understood.

Discriminant function. Yield as can be seen could be divided into a whole set of different components. For instance in rice, as in other cereals, there are the number of ears per plant, the number of grains per ear, and the weight of the individual grain. It has been recognised that certain of these components are more variable due to environmental conditions than certain others. In plant selection it is very necessary to know which of these are more stable and at the same time more highly correlated with yield, so that appropriate weight may be given to them in making selections. What the least variable attributes are can be determined only from replicated experiments and analysing the data by the new technique developed by Smith [1936] and Fisher [1936]. It is beyond the scope of this publication to discuss the problem; the original papers may be consulted for details. The 'discriminant function' developed by Fisher, provides a sound technique for selection, it provides a more comprehensive technique than any available at present in selecting for two or more components simultaneously, determines the role of each attribute with reference to yield and the value to be attached to them in breeding work.

Inheritance of quantitative characters. The plant breeder is mostly interested in quantitative characters, hence a study of their mode of action and inheritance is of importance. These characters are polygenic in nature, they may be controlled by comparatively few genes with large individual effects or by a large number of genes with varying effects. While there is immediate response to selection in both cases, it takes much longer time to achieve the maximum results in the latter case. In the study of the mode of inheritance of these characters, the ordinary methods of enumeration and reduction of results are not appropriate; suitable methods, however, have recently been suggested and work of Panse [1940], who has made a statistical analysis of inheritance of staple length in cotton may be mentioned. The study requires a sound knowledge of statistics and for details the original papers cited in reference may be consulted. It should be profitable to make a start with inheritance studies of the quantitative characters in rice along these new lines. Unfortunately the data available so far are not suitable for this study.

Deterioration. It is commonly complained that a strain 'runs out' after sometime. From a theoretical stand point of view it is difficult to understand how in self-fertilised crops a pure strain could 'deteriorate'. Nevertheless it has been found by Stadler [1924] that greater difference existed in wheat and oats between yields of different stocks of the same variety than between yields of different varieties. In the case of strains selected from natural populations such deterioration may be due to non-genetic cause as mixture of inferior types, natural crossing, unadaptability, etc., and to genetic causes such as segregation, and mutation. Sometimes the deterioration complained of by the cultivators may be the result of the exhaustion of the soil and the consequent fall in yield in spite of the fact that the strain is still genetically pure. In hybrid strains it is easy to perceive that this 'running out' is due to a residuum of impurity. Whatever the causes may be, it is desirable that the strains under distribution may now and then be tested for genetic variability in them. For this purpose the replicated progeny row breeding method is very well suited.

Selection within strains. The existence of deterioration in strains raises another important issue, namely, the question of further improving an established strain by secondary selection. In a crop like cotton secondary selection within strains is always practised leading to further improvement in characters like lint length, ginning percentage, resistance to wilt, etc. In the case of essentially self-fertilised crop like wheat, *jowar* and rice, while the technique of breeding in hybrid population does involve repeated secondary selection from progenies, the value of secondary selection in pure lines established by ordinary selection from natural population has not been investigated on any scale. It has been found from experiments at Indore that even in crops like wheat and *jowar*, selection within pure lines responds by way of increased resistance to lodging, resistance to disease, etc., though there was no actual increase in yield. Several years ago secondary selection was attempted in Madras in a strain of rice established by ordinary selection and when the new selections were compared against the original strain in a replicated trial it was found that there was practically no difference in yield between any of the secondary selections and the original selection. More recently at the Agricultural Research Station, Maruteru, it was found possible to improve an established strain, (Mtu. 8) by reselection with regard to particular form of chaffiness or sterility, which was present in the original strain. Thus a strain the purity of which is determined generally by its morphological characters need not necessarily be so for other characters, e.g. disease resistance, spikelet sterility, etc. When it is found that a pure strain is deteriorating, it may be possible that it is heterozygous for certain characters not detectable by eye judgment, and there may be a gradual accumulation of poorer homozygous types. When it is remembered that several of the quantitative characters that contribute to yield are governed by multiple genes, it may be expected there might be slight genetic variation with regard to these characters which the ordinary breeding technique could not bring out. It is considered that this question of secondary selection in rice, at least with regard to improvement of certain quantitative characters, should be examined more thoroughly.

The study will naturally involve special layouts to reduce the environmental effect to the minimum.

Mixture or pure strains. One line of attack in recent years in improveing yields is the question of growing strains as a mixture leading to the view that success in plant breeding may be considered as the production of well balanced and well adapted population. This may appear unscientific to people accustomed to orthodox views of pure lines, homozygosity, etc.; still, recent work in other crops has shown that there is some justification to consider the problem seriously. Selected strains in self-fertilised crops have proved superior to the unselected mixture of biotypes from which the selections were made, but it is generally found that the usefulness of such strains is rather limited while mixtures of suitable types have a greater utility over a wider range. A comprehensive analysis of crop mixtures has shown that in certain crops, there is a harmonious blending of the separate potentialities of the components of mixtures and each appears to be benefitted by the presence of the other. Titta [1934] concluded from the results of an interesting experiment, that continuous growing of a mixture of five varieties of winter wheat did lead to an increased yield every season so that after five years its annual mean yield was still higher than the annual mean total yield of all the relatively superior varieties grown separately.

With regard to rice in the large deltaic regions of India and Burma, where soil and other conditions are more or less uniform, it has been possible to isolate types which yield better than the unselected variety; there is no surety, however, that their superiority will be sustained under a different set of conditions. It has been found in Java that the moment, the soil and moisture conditions vary, the unit species or the pure lines fail. Suitable mixtures of four or five strains did better under such conditions than pure single types. It was also observed that the tillering capacity was higher in the mixture. Commercial or local mixtures are poor in yield because what nature selects is often below man's ideal, but genetic mixtures specially made may prove more advantageous.

How special mixtures of strains of a rice variety are useful over a wider range of conditions may be illustrated from the results obtained at the Rice Research Station, Maruteru, (Madras). Samples of the important varieties were collected from a number of places in the tract and when the large number of original single plant selections was boiled down to the best few as a result of yield trials, morphologically similar strains, five or six in number were mixed together and grown. From extensive trials it was found that the best of the components in the mixture did not excel the bulked mixture in yield, and these mixtures were also found to do well over a greater range of conditions.

HYBRIDISATION

The rice crop in India has been grown from a very long time, it consists of an endless varieties and the natural populations as found in the several regions provide a wealth of material to select from. With the plant breeding methods now in vogue in several of the provinces in India it may be confidently said that this variability could not have been exploited sufficiently, ordinary selection methods are still capable of giving satisfactory improvements. Hybridisation serves the purpose of creating variability in the material to select from. It may, however, be noted that at the Svalof

Institute. hybridisation is carried on side by side with selection work; the actual labour and time required in crossing work during the first two years is so small that it is regarded as a good practice to have always on hand hybridised material, at least of the F_2 generation, from promising sorts which are under trial and which may show possible improvements. Though reports of simple Mendelian segregations have almost ceased to have any interest at the present day, problems such as determining the effects of minor or modifying genes, determining the number and the effect of genes involved in particular inheritance, discovering the association of apparently visible and structural characters with the invisible yet fundamental characters concerned with the economic value of the individual, etc., can be studied only by hybridisation and enumeration of characters in the F_2 and subsequent generations.

Hybridisation has been practised in some of the provinces in India even in earlier years, in an attempt to improve the rices of those areas. In many cases, the hybrids did not give any direct improvement in yield over the parents that were crossed. Hybridisation was, however, found successful in a few cases where special physiological characters such as disease resistance, resistance to lodging, freedom from spikelet sterility, etc. were sought to be incorporated in otherwise desirable strains. The production of special hybrids, that could be easily distinguished from the wild rice in the Central Provinces illustrates how the inheritance of simple colour characters could be utilised in breeding programmes. Some of the factors that contribute to success in hybridisation programmes are detailed below.

Choice of parents. When the breeder has a clear picture of the type he wants to produce, the first question for consideration is the choice of parents as the final success of the work depends on this. The breeder is often confronted with the difficulties of deciding as to which parents would give the most promising material especially where there are several types having the same desirable character. Under such circumstances Fisher has advocated the use of the 'diallele' method of crossing. This method consists in crossing the types, say, A, B and C whose relative values are to be estimated with three common parent types say, D, E and F and comparing the variability of the several F_1s. The type amongst A, B, C which raises most the low parental value amongst D. E. F. is the most suitable for use as parent. This principle has not yet been tried out in plant breeding programmes in general and much less in rice. Vavilov [1940] advocates cyclic crosses among different ecological and geographical types belonging to the same botanical species. Anderson [1939, a] has discussed the difficulty in getting the ideal combination of characters by direct selection from the straight cross which is due firstly to the large number of genes governing the characters and secondly to the existence of linkage amongst them. He advocates secondary hybridisation between selections from the first hybrid which are most like one parent in one character and most like the other parent in the other character. This should particularly be useful in rice as for instance where a combination of high yield with a particular type of grain is desired.

Selection in hybrid progenies for yield. It has been a matter of great difficulty and it is still a puzzling problem for breeders to proceed selecting for yield from the F_2 generation. The chief reasons that make yield studies in hybrid progenies difficult in the earlier stages of selection are the effects of heterozygosity resulting in segregation, the presence of heterosis and the masking effects of environment such as soil, climate, etc. It has been suggested that heterozygosity can be reduced to narrow limits, irrespective of the number of genes contributing to the character in question by ten years of continuous selfing provided there is no linkage. But this is a fairly long period for one to wait; besides, there are no reasons to believe the absence of linkage. The best plan will probably be to carry forward as large a population as possible omitting structurally sterile and obviously undesirable plants to the F_3 generation and conduct a replicated progeny row trial and proceed with selection on the basis of these results. The procedure would minimise the effects of soil variations and give a valid estimate of the regression of the progeny means on F_2 values which may be used for selection from the F_3 plants. Similar trials may be conducted in the F_4 and F_5 generations also. Where a number of crosses made with the same end in view is available it may be useful to concentrate first on crosses that do not show heterosis to any marked degree. From theoretical considerations, the presence of heterosis may either be due to the accumulation of dominant genes or to the interaction of genes. In either case, the hybrid material should prove promising for selection. In the former, accumulation of dominant genes should mean that pure breeding forms, better than the parents, should become available by selection. In the latter, the interaction of genes should show considerable variability which should respond to selection. This question has, however, not been investigated thoroughly in any crop.

Collection of a wide range of material. The importance of a wide range of material has come to the fore-front in recent times due chiefly to the work of the Russian Botanists. They have shown that wild forms are storehouses of valuable genes governing resistance to diseases, drought and other adverse conditions. This aspect has still to be studied and made use of in the case of many of the crop plants including rice. Some of the rice breeding centres in India are making attempts in this direction, but a more intensive study would appear to be desirable. Even amongst the cultivated forms, it would appear, there is still a vast amount of unexplored material and this may with advantage be first collected and studied.

Interspecific hybridisation. Through the use of wide crossing, scientists abroad have been able to produce very valuable strains in other crops; very little progress has, so far, been made with regard to interspecific hybridisation in rice. Only a few interspecific crosses have been studied so far in India particularly in Coimbatore. The cross between *O. sativa* and *O. longistaminata* has given rise to certain economically useful forms specially with regard to drought resistance. It would seem desirable that more extensive studies are undertaken particularly with species that do not differ in chromosome numbers. The main point involved in crosses with wild types is the introduction of certain useful genes not present in the cultivated types.

The chief difficulty in pursuing crosses, where species differ in chromosome numbers, is the occurrence of sterility that accompanies them in the later generation. The F_1 may be completely sterile and all the work may have to be brought to a close. Recent developments have shown, however, that these sterile ones may be rendered fertile by (1) doubling of the chromosomes by colchicine and (2) by back-crossing the F to one of the parents, preferably using the one with the higher number of chromosome as the female parent. Colchicine treatment has been attempted in Coimbatore to render certain interspecific sterile hybrids fertile. but so far with no success.

Back-crossing. The principle involved in back-crossing is the simple one of reducing the amount of genetic variance in the material in which selection is practised. It is of value when it is desired to breed a strain deriving a great preponderance of its genotype from one parent and only a small proportion from the other. For instance, it is most successful when only one dominant character has to be transferred to a strain which is otherwise desirable in all respects. The procedure consists in crossing the two parents and back-crossing the F_1 to the parent to which the particular character is to be transferred for 2 or 3 generations and selecting for the character in each generation. This will yield a progeny identical with the second variety but heterozygous for the character being transferred. The desired homozygous forms will then be obtained on selfing. When the character to be transferred is recessive the programme must be extended by periodic selfings to bring to light the recessive character. Most scientists are agreed that this method has been particularly useful in increasing resistance to particular diseases in standard varieties. When it is desired to add resistance to two different diseases, separate programmes should be mapped out for each disease and the end product crossed together.

CHAPTER IX

METHODS OF SELECTION OF RICE FOLLOWED IN INDIA

SELECTION work which is almost a routine with plant breeders has been the most fruitful of results, success obtained by a particular breeder being proportional to the soundness of the technique he follows and to the extent of variability present in the material he is dealing with. It may be mentioned here that the methods of rice selection followed in the various provinces in India differ from each other in detail. The principle of selection rests with the exploitation of the variability that exists in a natural population. In any given rice tract there must be certain varieties limited in number but grown extensively and also others much larger in number but grown to a limited extent to suit particular conditions or requirements. Due essentially to admixture and natural cross pollination, no variety is botanically pure and there are ever so many variations to be seen in any given field where rice is grown. These variations which are easily discernible, are presence and absence of anthocyanin pigment in the various parts of the plant, differences in the colour of the grain (ripe lemma and palea) differences in the size of grain, presence or absence of awn, differences in flowering duration, differences in height of the plant, etc. Besides these variations there must be variation existing in the productive capacity of individual plants which may appear all alike so far as morphological characters are concerned. The breeder can make an exhaustive collection of all the varieties in a particular tract, isolate all the plants showing variations in morphological characters, grow them separately in the following year, give special numbers to whatever breeds true and maintain them as pure lines. This might be called *intervarietal* selection. Depending upon the size of the original material and the nature of cultivation in the particular tract, such pure lines isolated might be either few or large in number. Generally in a tract where no selection has been done previously and where no attempt is made to grow any particular variety in a pure condition and where the varying rice growing conditions necessitate the cultivation of a large number of varieties, such isolation of pure lines, if done exhaustively, can run into several hundreds. These pure lines are bound to vary in their productive power also and by comparing the progenies of each of these pure lines the best yielder or yielders can be determined. Where there is a very large number of such initial isolations, they are usually classed into several groups based on large differences, say, period of maturity, and the individuals within a group are compared against each other until the best one for that group is decided upon.

As different from the above, the breeder can confine his attention to one or two varieties only which are grown rather extensively in the tract and start selection work on them. Naturally in this case he does not confine himself to isolating plants which appear different in morphological characters but selects plants all of which look alike morphologically and judges their individual productivity by comparing their progenies. This is the progeny row testing and assumes for its success the existence in a natural population of a large number of biotypes varying in productive capacity. After a few years' trials the best yielder among the several single plants originally isolated can be decided upon, and this is multiplied and given to the cultivators as an improved type of the particular variety. This may be called *intravarie* selection.

In India both the methods mentioned above have been adopted. It must be admitted however that the latter method is the more reliable and it has given more enduring results wherever it has been adopted.

The earliest study of rice in India on an intensive scale was made by Parnell in Madras and Hector in Bengal. Parnell studied not only the morphological variations occurring in the collection of rice varieties, but also initiated isolation of single plants for progeny row testing in a few varieties to get at a strain that will yield better than the bulk samples of the varieties. This technique of selection from natural populations was later intensified by Ramiah, Parnell's successor, and applied to many of the important rice varieties in the major rice tracts of the Presidency, and this has resulted in the evolution of several higher yielding strains some times combining such useful adjuncts as earliness and better quality.

The number of single plants to be taken will vary according to circumstances. Where selections were made in cultivators' fields by gathering single heads the number taken was usually large, up to 1,000 in a variety. Where the samples were first grown in the experimental station with regular spacing and then selections made, the number was much less, 200 to 400 only. It was possible in some cases in the latter method to isolate better yielding strains even with as few as 100 primary selections.

Hector in Bengal believed that the morphologically distinct varieties within the great agricultural groups of *aus* and *aman* of Bengal with which he was working, were not so great as are commonly believed but the number of pure lines which could be selected from within each of these varieties was however very large. He was of the opinion that no hard and fast rule could be drawn between so-called *intravarietal* selection and *intervarietal* selection, and he followed both methods. His successors have however laid more stress on *intervarietal* selection only. Elaborate 'varietal' or 'pure line' trials were undertaken after obtaining them from the large number of existing varieties. These trials are run for three years and the best of them are recommended for growing by the cultivators.

McKerral and his successors in Burma have always used the single plant or progeny selection within a variety for evolving improved strains and worked with as many as 1,000 selections in each variety. The most important varieties of the tract, about four or five, were tackled at a time and improved strains evolved from them.

Graham [1911] in the Central Provinces had greater faith in the progeny selection in the best of the local types, which were first fixed from a study of the local varieties, and preliminary trails with them. This work was intensified later by Mahta and Dave. Later work by Dave in the Central Provinces lapsed into *intervarietal* selection only and he contented himself with comparing a large number of pure lines from varieties and issuing the best pure line as an improvement over the existing variety.

In the Bombay Presidency the second Economic Botanist, Chibber, adopted only progeny selection. Bhide continued the same method and his successor Kadam also adopted the same technique.

In Bihar, Alam [1931] first collected a large number of varieties and isolated all morphological variations and established hundreds of pure lines. These were then grouped into units and compared for yield to determine the best of them and so selection may be said to be that of *intervarietal* type only.

In the United Provinces breeding work on rice was taken up in the earlies of the last decade by Sethi. The procedure he adopted does not differentiate between the two methods of selection and appears to be a compromise between the two. As a matter of fact, most of the strains that have now been recommended in the United Provinces are the results of pure line or varietal comparisons only.

Mitra [1933] working in Assam has adopted only *intervarietal* selection as the basis, and the method is still in vogue for evolution of strains.

In Orissa improvement of rice varieties at present proceeds on a system of type collections in the varieties of several durations and trial of these types belonging to each group among themselves. It is practically the same as was adopted by Alam in Bihar.

In the States of Hyderabad, Mysore, Travancore and Baroda single plant selection within each of the important local varieties has been followed for evolution of superior strains. Where the number of varieties is large as in Hyderabad, the superior varieties are isolated by a system of preliminary comparisons amongst the varieties of the same duration and then the more important ones are taken up for single plant selection.

It may be interesting to compare the methods adopted in the other rice countries with those mentioned in India with regard to selection work. Three stages were followed in the improvement of rice strains in Japan; (1) Numerous local varieties from each prefecture were collected through the cooperation of the Imperial and Prefectural experimental stations and included in varietal tests and those best suited to each locality were selected to replace inferior ones; (2) after 1916, the selected local varieties mentioned above were subjected to progeny selection at all prefectural stations and (3) after 1927, hybridisation work was also organised at certain prefectural experimental stations, which represent different climatic sections of the country. Copeland [1924] reports that in Java *intravarietal* selection had improved the yield of Tagenrang rice. Viellard [1921] is of opinion that the cultivated varieties (these should not be confused with the botanical varieties) include a considerable number of fixed strains similar to those known in the botanical world under the name of subspecies or Jordan species. Each of these strains differs from the surrounding types of the same variety in characters of negligible importance morphologically but which mean a great deal from the cultural standpoint namely, yield, early maturity, etc., which are admittedly entirely transmissible to the progeny. In Indo-China pure line selection was followed by Carle [1925] in an important variety by which the yield was considerably improved. In the Philippines, collection of several thousand heads from twelve important varieties was made and the best strain in each of them was isolated later. In the United States of America every character is individually improved by *intravarietal* selection in the varieties under cultivation. Lord [1929] from Ceylon writes that ' Commercial varieties are composed of mixtures of different types which may differ in their hereditary constitution and which vary among other things in yielding power. In pure line selection a number of these types is picked out by observation and weight per earhead. After testing, the most suitable selection is retained. Yielding power, percentage of husk to grain, standing power, disease resistance, etc. are characters to be looked for in the strains'. Sands [1924], writing about the method of selection in Malaya states that as a first step, types were isolated from 300 varieties. Two varieties *Seraup* and *Radin* were selected for intensive work with 1300 single plants in each. These were grown as pure lines in triplicate plots for two seasons before any of the low yielding ones were discarded. Birkinshaw [1940] reports that the following standard procedure is adopted at three stations in Malaya with regard to rice improvement. 'Grain is collected at random in field from promising varieties, at least 500 single plant selections from each of the varieties, giving spacing in the row according to what obtains in the locality. Rejecting the weak plants, weight of ears from each of the remaining lot is determined and if sufficiently high, three good ears from each are taken for the ear to row selection. The aim should be to popularise one suitable strain in any locality rather than the distribution o a number of strains'. Poggendorff [1932] in New South Wales followed the single plant selection in the *Calore* and *Colusa* varieties and obtained superior strains in them. Lord [1929] reports of an interesting method of selection followed in Indo-China called the 'biologic selection' which consists essentially of rigorous selection not only between the progenies of different lines but also within the progeny of a single plant, combined with a careful botanical and agricultural study of different lines. The different stages of the method include:

(1) Morphological study of the variety—15 plants are taken.

(2) 200 seeds of each of these are sown with a standard for every three rows.

(3) From each of these lines four good plants are taken making a total of sixty plants.

(4) Lastly, these sixty are grown and four plants from each of these are selected making 240 in all.

These are studied for all characters and the best five or six lines kept for large scale trials.

Thus, all the rice workers in other countries are agreed on the point that each of the rice varieties grown in the cultivator's field is composed of distinct biotypes of varying potentialities with regard to many characters and also yielding power. It must be recognised that the ideal procedure in the improvement of a crop by breeding in any locality or region, is, first the determination of the most desirable and high yielding variety or varieties for that region or locality and the subsequent isolation of the best strains within those varieties. In the initial stages, by variety tests, the best variety suitable to the tract may be fixed upon. It is proper to begin progeny selection with a standard variety grown in the locality or with one recognised to be a heavy yielder selected from different parts of the tract. It follows from the method described that to get the best results each distinct rice tract must be dealt with individually. Selection in the local varieties can be done only in the tract itself. This should mean an experimental station, one for each of the distinct tracts. A province with several distinct rice regions should have at least one Rice Isolation Station for each region. Each station should begin in the most careful and thorough way the isolation of the best strain of the best varieties in the region. Where the cultivation of rice is new to a tract or where there are no varieties cultivated on a large scale, there introductions from other places and *intervarietal* trials may be successfully practised.

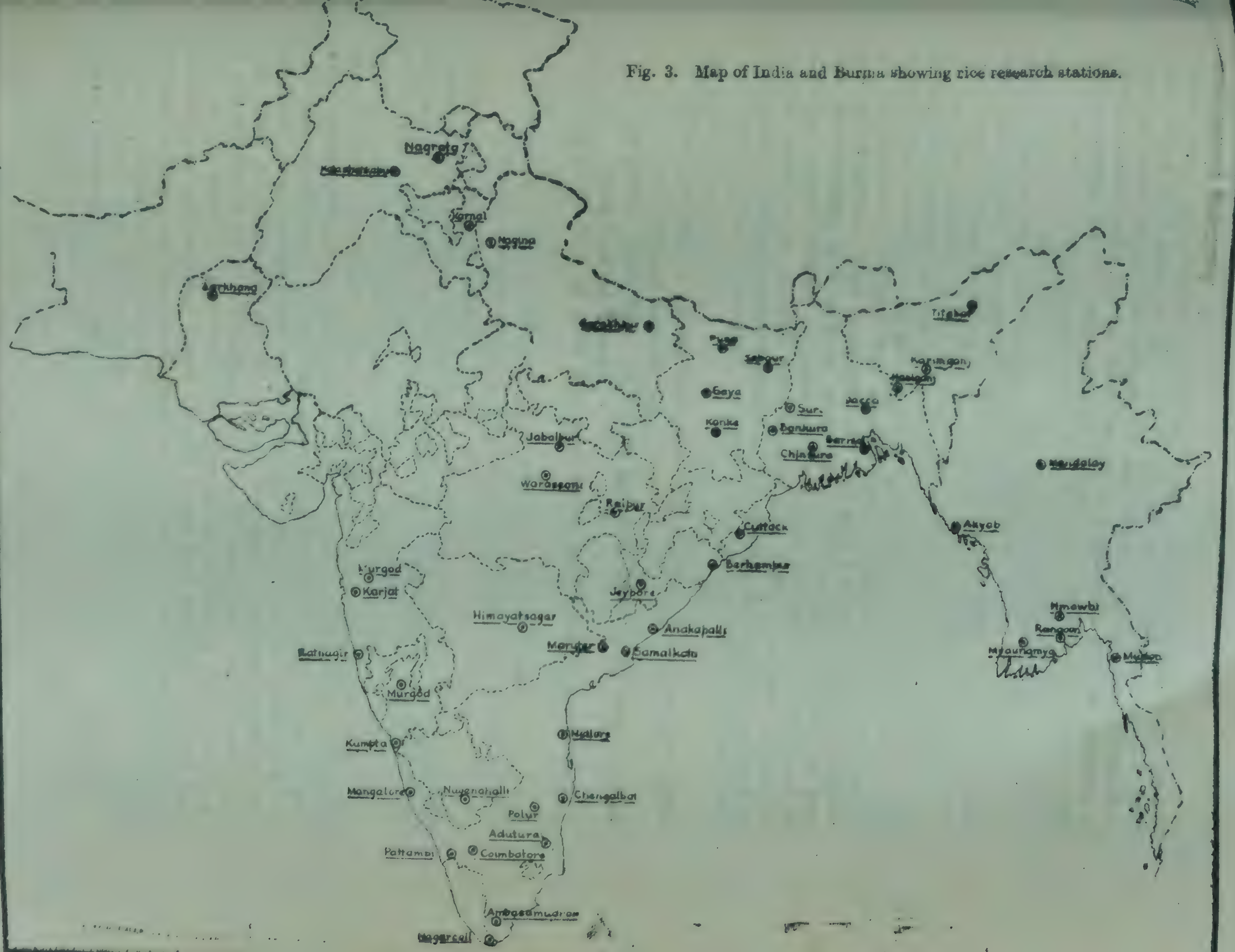

Nagrota
Karnal
Nagina
Jabalpur
Waraseoni
Raipur
Pusa
Sabour
Gaya
Kanke
Suri
Bankura
Chinsura
Dacca
Habiganj
Karimganj
Titabar
Mandalay
Akyab
Cuttack
Berhampur
Jeypore
Anakapalli
Samalkota
Maruteru
Himayatsagar
Murgod
Karjat
Ratnagiri
Mugad
Kumpta
Mangalore
Nugenahalli
Polur
Adutural
Pattambi
Coimbatore
Nellore
Chengalpat
Ambasamudram
Nagercoil
Hmawbi
Rangoon
Myaungmya
Mudon

Fig. 3. Map of India and Burma showing rice research stations.

CHAPTER X

RICE GROWING CONDITIONS AND PRACTICAL RESULTS OF BREEDING IN INDIA

IT is more easy to cultivate rice than any other crop so long as there is a plentiful supply of water available either in the shape of rains or special irrigation systems. Based on whether the crop is grown with irrigation or with the help of rain only, the cultivation of rice is divided into two categories, low land or wet rice and upland or dry rice. Rice area in India is mainly concentrated in the east in the provinces of Bihar, Assam, Bengal, Orissa and Madras. Since a large percentage of the rice area is dependent mainly on monsoon for its water supply, any uncertainty or weakness of the monsoon or occurrence of floods, cyclones, etc., affect the production. Owing to the great diversity in soil and climatic conditions under which rice is grown in the subcontinent of India, the season and methods of cultivation vary, and the number of varieties under cultivation is also very large running into thousands. The life period of the crop may vary anywhere between 80 days and eight months. At one extreme, there are the deep water rices of Bengal and Assam growing in 15—20 feet of water, and at the other extreme there are rices grown as a rainfed crop, sown either pure or mixed with cotton and red gram (*Cajanus cajan*) in lines. Though rice does best in heavy loams, it can be grown and is actually grown in poor sandy soils, shallow laterite soils as well as in deep clays in different parts of the country. It can grow in acid soils and it can also tolerate a fair amount of salinity. The range of p^H in soils which rice can tolerate is 5 and 8.5. Depending upon the fertility of the soil and water facilities, one may have a single crop of about four months' duration grown once in two years and three crops of rice, one following the other, in the same year and on the same land. With such diversity it is not possible to deal with the plant breeding achievements that have resulted in the whole country on a general unified plan. It has, therefore, been considered necessary to deal with the question province by province, giving a short account of the agricultural conditions and the results of plant breeding work.

Apart from the importance of the crop to each province, the nature and intensity of breeding work have also varied in the different provinces and States. Bengal, the most important rice province of India, was the first to start research work on rice with a special Botanist in charge of it. Madras soon followed Bengal, and it is only these two provinces that had a whole-time Botanist for rice work before 1930. The other major rice provinces either did not have a Botanist or the Botanist, when available, was dealing with other crops taking rice work as a side line only. Things, however, changed with the coming into existence of the Indian Council of Agricultural Research in 1929. Rice being the most important food crop of the country, the Council started financing rice research schemes in the different provinces and States. It was with this financial help that provinces like Bihar, the Central Provinces and the United Provinces were able to appoint staff. After a period of about ten years, the Indian Council of Agricultural Research gradually withdrew its financial help and the present policy of this body is not to finance purely plant breeding schemes which should be the concern of the provincial government. Wherever the provinces or States have their own research staff, the Indian

Council of Agricultural Research gives small grants for undertaking special agronomic investigations such as manurial and cultural experiments. The total amount so far spent by the Indian Council of Agricultural Research in financing rice research schemes, in the several provinces and States, is about 10 lakhs of rupees besides a special grant of two lakhs sanctioned by the Empire Marketing Board towards rice work in Burma and Bengal.

Besides providing financial aid, the Indian Council of Agricultural Research has brought about a considerable amount of co-ordination of research programmes in progress in different parts of India. The periodical meetings at Delhi and Simla have brought together the rice research officers who have derived considerable benefit in meeting each other and discussing common problems of research. It was at the instance of the Indian Council of Agricultural Research that a special committee of rice botanists met and drew up a standardised plan of studying the variability in the crop and describing the characters which has proved of great value to the rice workers in India.

BENGAL

With an average of 24.7 million acres which represents 80 per cent. of the cultivated area, Bengal has the largest area under rice and produces 9.0 million tons of rice annually.

The rice tract of Bengal may be broadly classified into four zones:

(1) North Bengal, mostly hilly, consisting of sandy or lateritic soil and traversed by a number of small rivers;

(2) Eastern Bengal, comprising the Madhupur tract with old alluvium and the new alluvium formation, both enjoying the benefits of heavy rainfall;

(3) Western Bengal with a fair amount of rainfall which is divided into two divisions, *viz.*, (a) the extreme west where the soils are of lateritic origin, but thrown into different levels, and (b) the delta portion in Central and Lower Bengal with rich alluvial deposits of rivers; the lower reaches of this portion are mostly marshy with salt encrustations in summer.

The average acre yield of the province is low and this is due not only to the growing of the crop very extensively in areas of varying suitability for the crop, but also to the dependence of a very large portion of the area on an uncertain and sometimes ill-distributed monsoon rainfall. This monsoon is often precarious in West Bengal while part of East Bengal suffers from want of drainage. The irrigable rice area is only 1.5 million acres or roughly seven per cent. of the total rice area. With the extensive cultivation coupled with the fickleness of the monsoon, cultivation of land has, out of necessity, to be quick and not very thorough.

The rice varieties found in the province can be grouped into five broad agricultural classes [Hector, 1930]. Though some of these rices are morphologically very similar, they are distinct so far as their adaptability to distinct regions and seasons is concerned. These groups are:

(1) Highland *aus*: (*aus* derived from Sanskrit *asu* meaning quick), Sown in April to May and harvested in August to September, dependent entirely on rains and is broadcast at the earliest

LIBRARY

opportunity; it is generally precarious and is followed in some areas by a cold weather crop of mustard or pulse.

(2) Lowland *aus*: Sown broadcast in low lands in February to March and harvested in August to September.

(3) Transplanted *aman* : The largest area is under this class of rice which is transplanted from seed beds sown in the month of June-July in semi-low lands and harvested in November to December.

(4) Lowland *aman*: Sown as No. (3) but planted on still lower areas and harvested in December to January when flood waters drain off. These are long stemmed rices and some of them can grow even in 20 feet of water.

(5) *Boro*: Sown in seed bed in the month of October and transplanted in December on the lowest areas of all, which do not dry up even in the cold weather, harvested about March.

A feature of rice lands of East Bengal is the cultivation of jute on the rich high land areas before a transplanted *aman*. The jute is replaced by *aus* rice in the event of a waning market for the jute fibre. The special high class *Patnai* rice of commerce that used to be exported to European markets is confined to the Sundarbans areas.

Being the most important crop in the province, rice received the attention of the Agricultural Department right from its inception and a whole time Economic Botanist was in charge of the work for a period of 17 years from 1911 to 1928. Dr. Hector was the first Botanist in India to start research work on rice and had made a very good beginning. He was succeeded by Mr. Sarangapani in 1928 and he was succeeded in turn by Dr. Heydayatullah in 1935. The experimental work on rice was first started at Dacca the headquarters of the Economic Botanist, representing the eastern zone. Fundamental research such as the study of the several varieties from the view point of morphological and field characters, observations on blooming, pollination and natural crossing, inheritance of anthocyan pigmentation in the several parts of the plant, etc., was undertaken and a vast mass of data was accumulated which has been detailed elsewhere.

Experience had shown that even in the same agricultural group, the selections evolved at the main station Dacca did not do well at the other rice areas due to the widely different climatic and soil conditions. The selection work was, therefore, decentralised and started in the respective tracts in the varieties peculiar to them. The problems connected with the Eastern Bengal were continued to be tackled at Dacca as before. The other centres of work were Chinsurah representing Lower and Central Bengal, Bankura for the drier regions of West Bengal bordering on Bihar and Orissa and Barisal devoted to types suitable to Sundarbans where saline conditions prevail. A substation was later opened at Suri in Western Bengal to represent tracts of still lower rainfall than Bankura. The procedure adopted at all these stations was more or less similar and consisted, besides collection of varieties and isolating pure lines in them, the following: botanical classification of the pure lines, study of inheritance of characters and hybridization among the selected types to breed still better ones. The results achieved at each station so far are referred to below.

1. Dacca Farm

Selection. Amongst the five agricultural groups of rices only two groups, high land *aus* and transplanted *aman* received attention. As a result of varietal trials with the pure lines conducted over a number of years, six *aman* varieties were recommended to the cultivators in 1922 (*vide* Appendix III). In the early years, work on *aus* consisted of extensive collection of varieties from the various districts of East Bengal and isolation of pure lines from them. Later, selection work was started with one hundred and fifty lines from each of the two varieties known as *Kataktara* and *Surjamukhi* and useful strains were evolved. Single plant selection was started in a very early variety called *Shaita aus* (70 days) in 1938. A small beginning was made to study the hill rices growing in the Chittagong area which has an elevation of 3750 feet above sea level and selection work was started in one variety named *Touli.* The long stemmed rices for deep water conditions within the early and late groups formed an interesting subject of study but for want of suitable facilities, work on them was deferred until 1925. The *aus* strains evolved at Dacca were put under yield tests at the Dinajpur, Rangpur and Rajashahi district farms in North Bengal and some of them were found to be useful.

Hybridisation. The aus varieties are generally inferior and coarse and the best yielders are not early enough to allow a second crop of rice. Hence with the object of combining earliness, high yield and good quality different sets of crosses between selected parents were made from time to time and the progenies therefrom studied. The *aus* and *aman* crosses were not however very successful as there was a good deal of sterility amongst the offspring. In the inter *aus* crosses three hybrids were fixed, P × S(8), D × S (28), and P × L(25). Crosses amongst *amans* were also made with a view to combine with high yields such characters like good quality rice, non-lodging straw and special grain sizes suitable for particular markets. Some of these hybrids are said to have produced the desirable types. For example, the crosses *Jhingal sail* × *Lati sail* and *Lati sail* × *Dudsar* have given two valuable strains 387-5-298 and 266-1-105 which await large scale field trials. Similarly the crosses between the local varieties and some of the Philippine rices have also given promising material.

Deep water rices. The second Economic Botanist stationed at Dacca devoted part of his time from 1925 onwards on the improvement of the long stemmed rices growing in deep water. There were, however, no facilities for regular trial of the deep water rices under suitable submerged conditions at this farm. But trials of several pure lines in an area near the farm where such facilities existed had resulted in the improvement of one variety called *Bisbais* which was however not the best amongst the typical deep water rices. A strain called No. 1 gave satisfactory results under six to seven feet of standing water, and two more pure lines *Maitchug* 834 and *Kala aman* 809, were also obtained to stand 13 to 14 feet of water. Crosses were also undertaken but due to want of proper facilities, the work did not make much progress. A few pure lines were isolated from amongst the several varieties grown in varying depths of water and this collection is being maintained.

2. Chinsurah Farm

The work at Chinsurah has for its object improvement of the rices of Central and Lower Bengal. The soils of this tract are quite rich but in the midst of plethoric plenty with a number of rivers, there is often dearth of water at critical periods of plant growth. Since selection made in Dacca did not do well here, collection of *aus* and *aman* varieties, common in the tract, was started and pure lines evolved from them. These pure lines were tested among themselves and as a result of this work a few from *aus* and a few from *aman* were recommended for growing by cultivators by the end of 1932 (*vide* Appendix III). Since 1932 the work at this station was elaborated with the financial assistance from the Indian Council of Agricultural Research.

Local varieties. The important varieties in the tract belonging to the *aus* group are *Kale, Bhutmuri* and *Jhanji* and intervarietal tests have shown the superiority of the pure lines from *Bhutmuri* and *Jhanji* and have been recommended to the cultivators. The pure lines evolved from the most important *aman* varieties were compared amongst themselves for some years and these trials showed that *Bhasamanik,* a pure line already under distribution was still the best, none of the lines evolved later surpassing it.

Patnai rice improvement. Special attention was directed to an intensive study of the *Patnai* rice which is chiefly grown in Sundarban tracts. Single plant selection was started in the variety in 1939, after obtaining samples from several places. The studies at Chinsurah Farm were supplemented by field scale tests at Sir Daniel Hamilton's Farm at Gosaba, but the latter did not always confirm the superiority of the strains selected at Chinsurah Farm. Two strains were, however, recommended for growing by cultivators. The work of isolating higher yielding types than these two is still in progress.

To evolve varieties with bold rices and flinty grains like the American *Blue rose,* hybridisation work was started in 1934 between *Blue rose* and a high yielding *Patnai* rice and between the heavy yielding *Latisail* and *Patnai.* A good *Patnai* type was also crossed with a Burma rice in 1937. Some crosses between the bold-grained, local *Hatipanjra* and the fine grained *Chingrighusi* and *Kalma* rices were also effected. In all, eight homozygous types with good grain quality and yield like *Patnai* rice were obtained from these crosses. These were compared for yield in trials at the Chinsurah Farm in 1941, against *Bhasamanik* and the local *Nagra* to see if there was a possibility of growing the hybrids in the inland areas where *Nagra* and *Bhasmanik* are common. Though the pure line *Bhasamanik* was the highest yielder, three of these hybrids were promising and gave higher yield than the local *Nagra.* The trials are being continued.

In the lower areas of Sundarbans, the rice crop is occasionally submerged and a lot of damage is done to the *Patnai* rice. Crosses were made between the *Patnai* rice and an *asra* rice which tolerates five to six feet of water to evolve a *Patnai* type which would stand flooding. The cross is still under study and some of the segregates are showing promise.

Improvement of other trade rices. Among the chief trade varieties particular to this tract other than *Patnai* which go under the name of *Bengals* may be mentioned *Nagra, Dadhkani* and *Kalma.* Extensive varietal trials were undertaken against strains of *Nagra* and *Bhasamanik* already under distribution. Though none of the pure lines tested was superior to the strains already under distribution, some pure lines being of better quality and giving similar yields are being recommended to the cultivators. The tract is also noted for its fine rices and pure lines evolved from them were compared in yield trials, and promising ones from varieties *Sitasal*, and *Rupsal* are being recommended. A selection evolved at Bankura from *Randhuniapagal* is also under distribution.

It would appear that with more intensive selection better yielding strains of *Bhasamanik* and *Nagra* could have been evolved. A large collection of pure lines amounting to 1,741 in number was being maintained at this station upto the end of 1940. It may be pointed out that this collection, based on morphological differences only, includes a large number of strains from the same variety; for example, 30 pure lines in variety *Nagra* are kept going. It would seem desirable to compare these strains among themselves and isolate the best of them for distribution as improved *Nagra*.

3. Bankura and Suri Farms

The station at Bankura was opened in the year 1922 and part of the area of the station was devoted to rice. With the appointment of a rice research officer in 1932 with finance provided by the Indian Council of Agricultural Research, the work at this station received an impetus. In the beginning, the several heavy yielding pure lines evolved by the Economic Botanist at Dacca were under tests with no conclusive results. This part of the country receives rainfall from June to October, somewhat less than the Eastern area, with the danger of an early cessation which is of frequent occurrence. The land is not flat and rice is grown under four well-marked situations, the highest one being called *danga*, the next three termed respectively *bad*, *kanali*, and *shole*. The production of early maturing, heavy yielding drought-resistant strains suitable to these different situations might be said to be the vital problem of the tract.

Selection. Work was started in 1925 and strains were evolved from the important local varieties for different situations. The work here was more difficult than at Chinsurah because of the uncertainty of the season. A selection from variety *Bhutmuri* proved to be the best for the highest situation, for the next lower one, strains from *Badkalamkati* and *Charnak* were found superior, for the third situation (*Kanali*) no selection was found superior while for the lowest situation, selection from varieties *Bhasamanik*, *Manik kalma* and *Raghusail* were found suitable.

Twelve hundred and seventy eight pure lines are being maintained at Bankura. Field tests of the several pure lines were simultaneously carried out under the four situations at the Suri Farm situated north of Bankura with greater drought conditions than at Bankura. Owing to the abnormal weather conditions, unevenness of the soil and the small field size, no conclusive results were obtained except certain general indications even after continuing the experiments for several years. In the highest situation, the same pure line of *Bhutmuri* found suitable in Bankura was about the best. In the next lower situation two pure lines from *Julur behar* and *Badkalamakati* (the latter the same as in Bankura) were found promising. In the third situation three types of *Paramanna sail*, *Nonaram sail* and *Boldar* were found promising for four seasons consecutively. *Bhasamanik* and *Sindurmukhi* were generally suitable for the lowest situation.

Hybridisation. Side by side with the inter-varietal comparisons, hybridisation was also started in 1934 between the high yielding local variety, *Lati sail,* and the American *Blue rose,* the object being to evolve early maturing and high yielding types with a bold grain like that of the American parent. Fifteen hybrids which were breeding pure in the F_6 generation were compared against the recommended strain *Boldar.* It was found that none of these approached the standard strain in yielding capacity but one of the highest yielding selections among the fixed hybrids had desirable grain characters. As the above cross did not give the desired results, crosses were effected in 1939 between *Blue rose* as one parent and each of *Nonarm sail. Jhinga sail* and *Ajan* as the other parent. The crosses are now (1942) in the F_3 stage and desirable material has been selected for further study. A few intervarietal crosses were also made to combine the hardiness of *Latisail* (though coarse-grained) with the better quality commercial type known as *Bengals,* (*Bhasamanik* and *Manik kalma*). The progenies are now in the seventh generation, selection being made on the basis of yield, tillering, quality of grain, flowering duration, etc. Results of yield trials has disclosed one hybrid from *Latisail* × *Bhasmanik* and two hybrids (Nos. 166 and 368) from *Latisail* × *Manik kalma* as higher yielding than *Bhasamanik.* These results have yet to be confirmed, and if the strains continue to be satisfactory they will be released for distribution.

Under normal conditions the tract has a small surplus but the difficulty at present has been that this surplus consists of a large number of varieties differing in size and shape of grain. The existence of different situations in these terraced tracts where the same variety cannot be grown, is a positive difficulty the grower has to face in producing large quantities of any one particular variety. With the idea of evolving different high yielding types for each of the different situations but all having the same size, shape and consistency of grain, which will facilitate the production of large quantities of similar types of grain, four crosses were effected between *Nonaram sail* (a medium sized grain type with good yield) as a common parent and four other pure lines found suitable for the four situations. The work is still in the initial stages of study.

4. Barisal Farm

This station was intended for studying the *Balam* rices of inter-provincial commerce, and also to evolve types suitable for growing under the saline soil conditions obtaining along the coastal tract. It was found that the variety *Chingrighusi* would answer the demand for a fine *Balam* rice. Selection work was started in 1936-37 within the varieties *Chingrighusi, Khiraijali* and *Bansiful* and the strains *Chingrighusi* Nos. 5 and 12, *Khiraijali* 8 *and Bansiful* 3 were found quite promising. These await further yield tests. Among the salt resistant types it was noticed that one variety *Hamai* did better than the rest. Certain strains from Hong Kong and Nigeria which were reported to stand salinity have been obtained, and are under study.

What remains to be done

Dacca

(1) No work has yet been started for North Bengal tract and so also in the *boro* group of rice.

(2) Work for the Southern hilly tract bordering Chittagong area is yet to be undertaken.

Chinsurah

(1) Though strain *Patnai* 23 is under distribution in the Northern corner, the obtaining of a still better strain, particularly for the north eastern area where the best *Patnai* rice is grown needs attention.

(2) Intensive selection within the two local varieties *Bhasamanik* and *Nagra* may usefully be undertaken to get higher yielding strains.

MADRAS

The agriculture of the Madras Province differs from that of other provinces of India in that it is characterised by the dominance of rice and millets among food crops, the two being complementary to each other. Rice occupies about 11 million acres which forms 30 per cent of the total area under crops with a production of 4.7 million tons of rice. Madras along with the neighbouring States, Travancore, Cochin and Mysore is the chief rice deficit area, and more than two thirds of the pre-war rice imports from outside were utilised here. The rice culture in the province is probably the most varied of all the provinces in India. The following definite rice growing areas can, however, be distinguished:

(1) the Malabar coast with a heavy rainfall of 100 inches and more, undulating land with low hills and shallow valleys between, the soil lateritic, shallow and poor. On the higher slopes rice is grown once in two years and lower down a single crop of rice is grown every year on terraced fields; further down in the valleys two short crops of rice, one following the other are raised;

(2) the central and southern districts with a low rainfall of 20 to 30 inches where the influence of both the monsoons is felt; primarily irrigated from seasonal rivers and supplemented by water stored in tanks and wells;

(3) the districts on the Eastern coast with a higher rainfall than in the Central districts cultivated mostly during the north east monsoon (October to February); and

(4) the delta tracts of Cauvery, Kistna and Godavary rivers which have amongst them 50 per cent of the total rice acreage, with an elaborate and efficient irrigation system supplemented by rainfall from both the monsoon; the soils here are deep and are rich alluvium in the Cauvery delta, black and stiff clay in the Kistna and Godavary deltas.

A peculiar feature of rice cultivation in the province is that the crop can be seen in some part or other all the year round. Over ninety per cent of the rice area the practice of transplanting obtains, and eight million acres are protected by irrigation. There is likely to be further increase in the irrigated area with the completion of the Bhavani and Tungabhadra projects.

Work on rice crop formed an important activity of the Agricultural Department from the very beginning. Though no intensive botanical work was attempted in the earlier years, the improvement of cultural and manurial practices received considerable attention.

From the very outset a progressive policy with regard to rice research had been followed by the Government which consisted of: (1) the appointment of an expert botanist and plant breeder to examine the crop, its distribution and possibilities and plan a campaign of improvement work; (2) establishment of a central breeding station at the Research Institute at Coimbatore with necessary laboratories, equipment and research staff. (3) establishment of substations in the main areas devoted to the crop and evolution and testing of special strains to suit local climatic and soil conditions and special markets (such substations were manned by staff trained at the central station), and (4) intensive study of manurial, cultural and irrigational problems connected with the crop in the different tracts. The first Economic Botanist appointed in 1912 (later designated Paddy Specialist) concentrated his attention on rice and Mr. Parnell, who is now a famous cotton breeder in South Africa under British Cotton Growing Corporation, was in charge of this section from 1912 to 1924. Mr. Ramiah, who had worked as Parnell's assistant almost from the very beginning, succeeded him. The opening of several substations and a general expansion of rice work in several directions took place during his time. In 1937 Mr. Ramiah was succeeded by Mr. Sreenivasan, who is now in charge of the rice work in Madras.

With a preliminary rough survey of the rice crop in the Presidency, the Paddy Specialist set himself to the breeding of superior strains by selection, as the most direct method of obtaining results of economic importance. There was already available a large collection of varieties in Coimbatore. Studies on the genetics of the crop were also taken up in addition to the economic work at the central station mainly to understand the variations in the several characters that occurred in the varieties that were being grown. Most of the genetic results discussed elsewhere have come out of this work. The plant breeding results achieved at each of the stations are given below.

1. Paddy Breeding Station, Coimbatore

The rice season of the tract extends from the middle of June to middle of January. Since the rainfall during the rice season hardly amounts to 20 inches, the crop is mainly dependent on irrigation from a canal-fed tank and even this has at times to be supplemented by lift water from wells. Only one crop of rice of 5 to 6 months in duration is grown and the crop is always transplanted. The practice of either growing a green manure crop or ploughing in green leaves collected from hills and jungles in the neighbourhood is general. The soil is clay loam with good drainage.

Selection. The varieties of Coimbatore and neighbouring districts as also many varieties from other important rice tracts were collected to ascertain the range of variation that existed in rice. The local varieties received attention first and later the varieties of minor rice areas in which the conditions of rice growing were somewhat similar to those in Coimbatore were also taken up. Following the method of progeny selection work within each important variety, testing the best of them first at the research stations and later in cultivators' fields on a large scale, several useful strains (*vide* Appendix III) have been evolved and are under distribution. Special mention has to be made here of th outstanding strain Geb. 24, a creation of Parnell and his assistants, selected as a natural mutant in a variety called *Konamani* from the Godavary delta, which has been showing a great range of adaptability in the province and even outside India. It has gained a trade distinction and is called *Kitchili* in commerce (Plate VII). From an examination of the details of information about these strains, it is seen that all these strains have given higher yields than the unselected bulk from which they were first isolated, and possess in addition such useful characters as better quality rice, higher milling outturn, and in several cases reduction in duration as well.

Hybridisation. Though a large amount of hybridisation work has been done from the very beginning, it was mostly connected with genetical studies. Since ordinary selection had itself offered great scope, hybridisation for economic ends was not started until some years later though the possibilities were visualised even as early as 1917. Some of the earlier crosses undertaken with economic ends in view while providing interesting information on the inheritance of quantitative characters as length of ear, tillering, duration and their inter-relationship on which the yield of the plant depends, failed to produce the desired results. The appearance of the parental type was the only criterion to go by in choosing it for crossing. But as work progressed and the study of genetics was made a regular programme on the station, more information about several characters was available, and hybridisation was undertaken with greater confidence. Among others two outstanding products of successful hybridisation work may be mentioned, *viz.* (1) the production of *piricularia*-resistant strains, and (2) the evolution of non-lodging types suitable for partly submersible tracts.

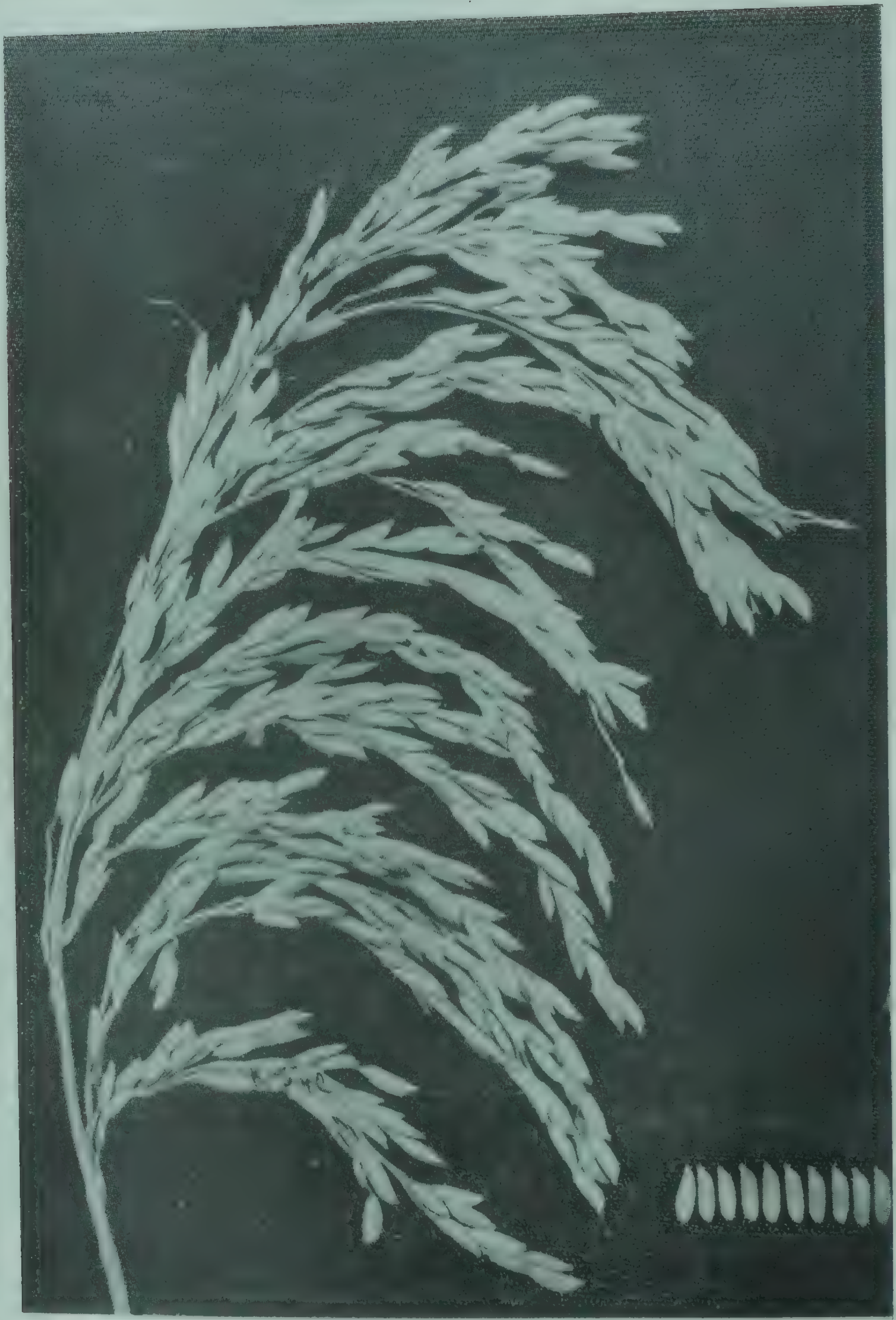
(i) *Piricularia-resistant strains.* A variety from the Tanjore district called *Korangusamba* and a popular variety of the Nellore tract named *Molagolukulu*, both of long duration, are subject to the blast disease, (*Piricularia oryzae*), which in certain years caused damage up to 50 per cent. of the crop. Geb. 24, a strain evolved at Coimbatore, and later another strain Co. 4, were found to be fairly resistant to this disease and crosses were effected between the susceptible *Korangusamba* and the two resistant strains. Two strains, Cos. 15 and 16 were obtained out of the first cross and two further strains, Co. 25 and Co. 26 still better than 15 and 16 have come out of the second cross.

(ii) *Non-lodging strains.* Strain Co. 3 from a medium duration, long grained variety of Coimbatore which is a favourite with the cultivator has a very bad tendency to lodge and also to shatter its grain badly in the field if harvesting is not done in time. These two defects were sought to be remedied by crossing it with an erect, stiff-growing Burma variety. Following the selection to the F_6 stage two progenies were obtained. But it may be pointed out that the non-lodging, good-yielding progenies in this cross did not possess the fine grain size of Co. 3. One of the progenies was also found to stand a certain amount of submersion and it was released as Co. 14 for cultivation in such areas.

A large number of crosses to improve the quality of certain strains and yield of certain others, to evolve high-yielding good quality rices with short duration, strains of good quality resistant to saline conditions, etc., have been made and they are at different stages of study.

Inter-specific hybrids. In the course of studies on a cross between strain Geb. 24, (*O. sativa*) and a wild species *O. longistaminata* which is

A good crop of Geb. 24. (Madras)



Earhead of 'Chanchala', Premier Kolamba strain (Bombay) common in the swamps during monsoon and remains dormant when the swamps dry up, it has been found possible to breed some valuable types which withstand drought better than some of the varieties under cultivation. These are intended to be tried in the tracts with indifferent water supply. These types are very similar to Geb. 24 but the duration is considerably increased and these might prove useful in other parts of the Presidency where late varieties are in demand.

X-ray mutants. Following modern developments in plant breeding, namely, the production of mutations of X-ray, colchicine, etc., Coimbatore was the first in India to try X-raying rice seed in the year 1933. The seed of the outstanding strain Geb. 24 was subjected to X-ray treatment and the several mutations obtained were of great genetical interest and are dealt with elsewhere; mention might here be made of one mutation which has proved of economic value. This resembles the parent in all respects but has better tillering capacity than Geb. 24 and is even somewhat finer in grain size than the same. Comparative trials with the mutant have shown that it responds very well to heavy manuring. Some other selections from the X-ray progenies are under comparative trials in the several tracts.

This station has built up a large range of varieties, Indian and foreign, and the maintenance of genetic stocks including wild species is an important activity. A study of the variations in this big collection forms a highly useful training ground for beginners in rice research.

2. Agricultural Research Station, Aduturai

This first substation was opened in the year 1921 at Aduturai to serve the Cauvery delta which has a million acres under rice every year. The number of varieties grown on an extensive scale in this tract is not many and these varieties were taken up for improvement by progeny selection first and later by hybridisation.

The three cropping seasons of this delta are the *kuruvai* or early first crop season from June to October, the main *samba* season on single crop lands extending from August to January and the *thaladi* or second crop season after the harvest of the first *kuruvai* crop and extending from October to February. In a small area particularly in the lower reaches where water is received late, and there is not sufficient interval for harvesting the first *kuruvai* crop, ploughing the land and transplanting the second crop, an ingenious practice obtains of mixing *kuruvai* seed with a 8 months variety, (*ottadan*) in the proportion of 4:1, sowing the mixture in the seed bed and transplanting the same in July. The *kuruvai* is harvested in October and the *ottadan* stubbles shoot up again and give a crop in the following February. Experiments on the station have shown that there is always a balance between the yields of the two varieties grown as a mixture. When the season is favourable and the early *kuruvai* crop yields well, the yield of the later *ottadan* crop is low and vice versa.

Selection work. Even before the Aduturai station was opened, selection in three or four of the important varieties of this tract was undertaken at a temporary station, Manganallur, in the area by periodical visits of the Coimbatore staff to this station. When the Manganallur station was closed down, the material on hand was transferred to Aduturai and within three years, seven strains were ready for distribution. In the course of the next few years fresh varieties which required improvement were taken up and strains were evolved from them (*vide* Appendix III). Selection work in some of the less important varieties of the tract is now in progress.

It may be noted that one strain (Adt. 15) was spotted first as a spontaneous mutation in a field of an established strain Adt. 4 and by mere isolation and multiplication it has been found to yield 16 per cent more than Adt. 4.

Hybridisation. (i) *Piricularia-resistant strains.* This work has already been referred to under Coimbatore. It is more or less supplementary to Coimbatore work as the problem is more acute here. Crosses between *Korangu samba*, a susceptible variety with Geb. 24, a fairly resistant strain had given a progeny with heavy yield, fairly resistant to *piricularia* under field conditions and resembling the susceptible parent in other characters.

(i) *Early sirumani strains.* A case in which hybridisation was undertaken to break the type and bring about greater variability in the material may be cited. One of the popular varieties called *White Sirumani* did not show any variability and failed to respond to simple selection. Crosses were, therefore, effected between the best strain in *White Sirumani* (Adt. 2) with a number of similar morphological types. Though the progenies from these crosses failed to give any type with greater yields than Adt. 2, one selection was found to mature fifteen days earlier without any reduction in yield and this was a great consideration for the cultivators as the variety is usually grown as a second crop when water difficulties might be present for a late variety.

(iii) *Fine sized, short duration strains.* Another successful cross refers to the improvement of the grain size of the coarse and inferior short duration *kuruvai* varieties. The small round size of grain which is preferred in certain markets and which is usually found in long duration varieties has been obtained in a hybrid type with *kuruvai* duration.

3. Agricultural Research Station, Pattambi

The tract has (wet) single crop, double crop and dry rice areas. All the crops depend entirely on rainfall during the two monsoons amounting to over 100 inches. The typical wet area cannot be seen in any unbroken stretch as in the east coast but is confined to patches of 50-200 acres in extent in the valleys of low hills.

While the dry crop on the ridges and higher slopes of low hills is always broadcast, the crop in the terraced fields and the first crop in the valleys are either directly sown or transplanted. The second crop in the valley is always transplanted. The soil is all lateritic, shallow and poor except in the valleys. Usually all kinds of green leaves chopped from avenue trees and forests are trampled in for the first crop in the wet area. Most of the local varieties are coarse with red kernel, and in fact there is a preference for red kernelled varieties in the tract.

Selection work. As the first method of improvement, methodical progeny selection which had been developed at Coimbatore was applied to the more important rice varieties of the tract. An experience that must be recorded here was that in some varieties the cultures obtained from a limited area did not respond to selection probably for want of sufficient variability and often fresh material from a wider range had to be collected and selection work restarted. In many of the local varieties strains giving definitely higher yields than the local bulks were isolated and made available to the cultivators (*vide* Appendix III).

Hybridisation. With the large number of varieties to be tackled and with the early promise of good strains by ordinary selection on them, hybridisation did not receive attention on any scale at this station. However certain crosses were done later as for instance, between Ptb. 4 × Geb. 24, Ptb. 4 × Co. 3 and *Kavinginpoothalae* × Geb. 24. These are at present in F_6 generation.

4. Agricultural Research Station, Maruteru

To cater to the needs of the Godavary delta, more especially the west and the central portions, with an annual area of 1.5 million acres under rice, a station was opened in 1925 at Maruteru in the western delta. It may be mentioned here that this area is the richest, recording the highest average yields in the whole of India. The rice season of the tract begins in June when freshes are received in the Godavari, and on a large percentage of the area a single crop is grown between June to December. A small percentage of the area gets water for raising a second crop between February to May. The crop is always transplanted. Besides the rainfall of about 40 inches received in the season, the crop depends upon canal irrigation and since these canals are used for navigation purposes as well, there is water available for 11 months in the year. The growing of sann hemp (*Crotolaria juncea*) and *pillipesara* (*Phaseolus trilobus*) both for green manuring and feeding to cattle is a general practice obtaining in the tract.

The soil is heavy black clay and cracks widely in summer so much so, that very little preparatory cultivation is found necessary. There is never any shortage of water supply in this tract; in fact, the question of drainage is more important particularly during the north east monsoon period. The work on the station started with a survey and collection of the more important local varieties. Fortunately the number of varieties grown in the delta is few and these varieties have large concentrated areas under them so that any improved strain would go to benefit a wide circle of cultivators.

Selection. The cultivators of the place are very enlightened and to meet the keen demand for good seed, mass selection was resorted to in the very early stages and the produce was supplied to the people. Selection work from varieties grown in the Kistna delta which is contiguous to this delta was taken up at a later stage as there was a pressing demand for improved seed from the cultivators there. Preliminary selection and study were done on the station followed by actual testing of the strains simultaneously on the farm and also on the cultivators' fields. This work has so far resulted in the production of 14 improved strains which are under distribution to the cultivators (*vide* Appendix III). These improved strains have gained considerable popularity and it is no exaggeration to record that more than 50 per cent of the area in the delta is now cropped with the improved strains from the station. It may be pointed out here that it was at this station that a composite mixture of strains was tried which has been referred to in an earlier chapter. The purity of these bulks and strains is being tested every five or six years after they are distributed by selecting a random group of 200 plants or ears and growing them next season. Those progenies which show any variability are rejected, and the rest again grouped and made the foundation of nucleus for further multiplication purposes.

In the course of extensive trials of the improved varieties evolved at the station it has come to light that they are better adapted to differences of environment than the cultivators' seed from which they were originally selected and gave a better response to manuring practices (*vide* Table IV).

TABLE IV

Behaviour of strains under manured and unmanured conditions at Maruteru (yields expressed as percentage)

Particulars	Strain 1	Strain 2	Strain 3	Cultivators bulk
Variety *Krishnakatukalu* (Rich soil)				
Manured	112	118	128	107
Unmanured	102	104	118	100
Variety *Akkulu* (Rich soil)				
Manured	103	117	128	100
Unmanured	102	113	128	100
Variety *Akkulu* (Poor soil)				
Manured	115	121	128	109
Unmanured	99	121	128	100

Upland rices. Along the east coast just west of the central irrigated areas rice is grown on the black cotton soils as a rainfed crop under open conditions either pure or as mixtures with cotton and red gram (*Cajanus cajan*). This practice is very similar to that obtaining in parts of Bombay and Baroda. Selection work on these rices was undertaken on a private farm and later hybridisation work was also undertaken to evolve high yielding, better quality types along with introduction of types reputed to stand drought. While it was possible to isolate some high yielding strains in the varieties of *Budama* and *Jilama*, the two most popular varieties, no introduced variety was found useful. Some promising material has been obtained from the hybrid progenies and is still under study.

Hybridisation. In the early years a number of natural crosses occurring in the station were under intensive study for fixing any useful combinations that might result, and 2 useful strains have been obtained. The first was a selection from a natural cross *Badava kusuma*, occurring in a floating deep water rice introduced from Burma and is found to grow very vigorously in the initial stages and able to withstand mechanical forces of floods up to four feet, if the crop is not less than 45 days old at the time of flood occurrence. The second strain was derived from a natural cross between *Nallarlu* and *Garikasannavari* the largest grown second crop variety of the delta. The extracted hybrid does not shed its grain like *Nallarlu* and does not lodge to the same extent as *Garikasannavari*, but at the same time gives higher yield than the *Garikasannavari* strain under distribution by about 15 per cent.

Hybridization was undertaken later on at the station with the object of improving the yields of some of the low-yielding strains, making the size of grain more attractive in others, reducing the chaffiness yet in others, etc., and these crosses and back crosses are now [1942] at different stages of study.

Second crop problem. Though this does not strictly come under the purview of plant breeding, the peculiarity of the problem would be a sufficient apology for detailing it here. The problem of the second crop is that although the first crop is harvested in November, no rice crop thrives well when planted from December to January inspite of the fact that there is plenty of water available in the canals then. Any crop planted earlier than February does not tiller and is subject to insect pests, particularly stem borer, and the yield is very low. The second crop is successful only when it is planted in the beginning of February. This February planted crop however often suffers for want of water during the flowering season in April when water is low in the canals. Experiments were carried out at this station with a view to finding out if cultural practices or introduction of other early varieties would improve the situation. It was observed that none of the short duration varieties tried could be planted before February with success. But a cultural device applied to the nurseries has been found useful. This consists in sowing the seed beds for the second crop quite early in the month of December and letting the bed go completely dry after the seedlings have attained sufficient growth and until they are required for planting. These seedlings when planted even in the middle of January do not suffer so much and ripen off earlier than the seedlings raised under the usual methods. This practice has been recently introduced in the area and would seem to be slowly gaining favour with the cultivators wherever the problem is very acute.

5. Rice Research Station, Berhampur

Selection. While the previous substations were opened permanently with provincial finance, the financial assistance of the Indian Council of Agricultural Research was taken in 1932 to open a temporary station for a period of five years at Berhampur. Since a large portion of this area comes under Orissa and as the formation of this province was under consideration very soon after the opening of this substation, the programme of work was so arranged that at the end of five years when the station was to be handed over to Orissa, definite strains of the most important local varieties would be made available. The intensive programme of selection and trial of few strains was quite successful and by 1937, strains suitable not only for Orissa portion but also for the area left in Madras were actually available. The strains evolved are described in Appendix III. It may be mentioned that the Ganjam district is rich in the number of fine rices and selection work on these was also undertaken later and these have been continued by Orissa, details of which are given under Orissa.

There is a demand in this area for short duration types which are confined to the high level fields and for this situation selection in two of the important varieties was undertaken in 1934. A strain in each of them has now been released [1940] by the Orissa Department.

Hybridisation. A popular medium duration variety with several desirable characters and suitable for semi-wet cultivation called *Boroponko* was crossed with a white-riced variety called *Bennubhogi* in 1934. A selection from this cross named Bam.11 has since been released in 1941 which has not only white rice but also gives a somewhat higher yield than the best strain in *Boroponko.* Similarly a hardy, red riced variety suitable for submersible tracts called *Duddamani* was crossed with Geb. 24 to produce an equally hardy type like *Duddamani* but with white rice. Suitable types have now been selected from progenies of this cross. The wild rice growing in low lying marshes belonging to the species *Oryza longistaminata* was crossed in 1935 with a cultivated variety more for academic studies, but it was found that the progenies contained amongst them very good forms with tall growing habit and partially resistant to drought. These are being studied by the Orissa Department of Agriculture and are referred to there.

6. Agricultural Research Station, Chingelput

A major substation was opened at Tirurkuppam in 1942 for the area having nearly a million acres under rice. This tract is characterised by a large number of irrigation tanks and wells which form the source of irrigation for the crop. Besides the above, there are large areas under dry rices grown with the help of the monsoon rains only and other large areas where the crop is first treated dry and is later converted into a wet crop with the break of the north—east monsoon. This station would cater to the needs of all these conditions. Studies so far made have given certain high yielding selections in the different groups which are ready for trial in the district before release.

The expansion of the rice work in Madras was visualised as having two types of stations. One is of a permanent nature with a fairly large area, over 50 acres, with self contained staff where all aspects of rice cultivation along with breeding could be undertaken for each of the major tracts which have about a million acres and more under rice. The stations at Aduturai, Maruteru, Pattambi, Berhampur and Chingelput come under this category. The second type of stations is of a temporary or semi-permanent nature, considerably less in area, 10 to 15 acres only for each of the minor tracts having about 100,000 acres and more under rice. The staff here is limited, and breeding is the main consideration. Among the tracts coming under this category the following three (7, 8 and 9) have now got small stations of their own.

7. Rice Research Station, Buchireddipalem

To improve the trade variety *Molagolukulu* or *Nellore samba* as it is known, which is grown on about 2,00,000 acres and which has a high reputation as good raw rice in the South Indian markets, this station was opened in the Nellore district in 1937. This tract grows only a single crop of rice and the season extends from August to February. The crop is dependent on irrigation from river channels or from large reservoirs and also gets the benefit of the north east monsoon rains to the extent of 30 inches. Though transplanting is the main practice, direct broadcasting also obtains when the season is late. The planting of the crop may be done any time between August and October depending upon the receipt of water in the canals. The variety *Molagolukulu* is the chief variety grown in this tract. The soil is either loam or sandy loam.

The pressing problem of this rice area is the breeding of blast

(*Piricularia oryzae*) resistant types as the most widely grown variety *Molagolukulu* is particularly susceptible to it. It has been estimated that there is an annual loss of about 25 lakhs of rupees in this tract due to this disease. The problem is, however, slightly complicated by the indefiniteness of the planting season due to the vagaries of the monsoon. The general experience has been that the disease is particularly severe under late-planted conditions. The main work of this station has been devoted to the evolution of *Piricularia* resistant strains in *Molagolukulu* which can also stand late planting. Strains Co. 15 and Co. 16 evolved at Coimbatore by hybridisation which have been found to be blast resistant in the southern districts are also found to be resistant at this station but they lack the quality of *Molagolukulu* grain. A search is, therefore, being made to find out if any resistant strain can be isolated from the variety *Molagolukulu* itself. A large number of selections, about 1,500 made from samples obtained all over the tract is under study since 1937 both under early and late planted conditions, and two strains BCP. 1—*Sanna Mologulukulu* and BCP. 2—*Potti Mologolukulu* which are high yielding and also more resistant to the disease than the local cultures have been obtained. The alternative of producing a resistant strain by hybridisation is also receiving attention by crossing the susceptible *Molagolukulu* with a resistant strain. Resistant material from Coimbatore is also being tested under local conditions.

Improvement of other varieties which are comparatively less important than *Molagolukulu* such as for example, *Atragada, Sannavadlu* and *Pishanam* by selection is also in progress.

8. Rice Research Station, Ambasamudram

This temporary substation was opened in 1937 for work on rice varieties of the Tamparaparni valley which has a rice area of 2,50,000 acres. The season begins with the break of the south-west monsoon in June. At the upper portions of the valley due to early receipt of water and an unfailing supply two crops are raised, a short *kar* crop with red kernel between June to September followed by a long duration *pishanam* crop with fine white kernel, from September to February. In the lower portions of the valley where there is no assured supply of water there is only a single long duration *pishanam* crop.

The soil is usually red sandy loam well drained with a substratum of gravel. The work as in Buchireddipalem is confined to various aspects of plant breeding in the local varieties. Even before this station was opened a certain amount of preliminary work had been done at the Central Station, Coimbatore, and this considerably facilitated the subsequent work at the station. After completing the comparative trials of strains already selected in Coimbatore at this station the best of them were quickly multiplied and are being made available to the cultivators.

In addition, an extensive study of the local varieties belonging to first and second crop seasons was undertaken at the station and progeny selection started on the most important of these. The attempts have been successful and strains of high promise have been evolved from them and are under cultivation.

9. Agricultural Research Station, Mangalore

A substation was opened in the South Canara district in 1942 near Mangalore to improve the varieties of rice in this district which occupies nearly 2,00,000 acres. The varieties and conditions here differ from those of South Malabar where Pattambi station is situated.

So far, only the stations actually started by the Paddy Specialist and those which had remained under his control all along or during the early years, have been mentioned. In this province there are also other experimental stations where rice is under study and these are dealt with below (10 and 11).

10. Agricultural Research Station, Samalkota

This farm was opened in the East Godavary delta in 1908 mainly for the study of sugarcane. Rice which is grown in rotation with it has also received some attention. The rice work included besides agronomic experiments, selection in some of the more important rice varieties of the tract. It may be mentioned that the varieties of this part of the delta are different from those grown in the west delta of the Godavary, dealt with under Maruteru. The soils here are more alluvial making it possible to grow a good pulse crop or Gingelly (*Sesamum indicum*) after rice. A few outstanding strains in the local varieties (*vide* Appendix III) have been obtained.

11. Agricultural Research Station, Anakapalle

This farm which is similar to Samalkota is mainly a sugarcane station but a certain amount of selection work on rice has also been done. Some strains useful for the large rainfed tracts of the Vizagapatam district were evolved and some of these have later been replaced by better strains available from the Rice Research Station, Berhampur.

Strains too many

With regard to the number of strains evolved in Madras, it is already considerable, due perhaps to the more systematic lines of plant breeding work carried on over a much longer period than in any other province. It is also the result of undertaking breeding work in the several rice tracts independently. Owing to the limited adaptability of particular improved strains which is characteristic of this crop, a large number of strains suited to different soil and climatic conditions and to suit variations in seasonal and cultural practices is inevitable. It has also to be noted in this connection that all the strains evolved are not necessarily of equal importance. For example, the strain Geb. 24 evolved at Coimbatore occupies the largest area in the Central districts than any other single strain. Of the several strains available at Maruteru, (*Bontha Akkukulu*) Mtu. 1 and (*Bontha Krishnakantukalu*) Mtu. 5 are the most popular. In Aduturai, *Nellore Samba*, Adt. No. 11 is more popular than other strains. There have also been cases where a strain seemingly not attractive at first, has become extremely popular later. A good example of this is Mtu. 4. Certain strains as Mtu. 16 or Co. 14 are suited to areas which are subject to submersion with three to four feet of water during the cropping season. There is also the fact that varieties do not maintain their popularity always. After a period of time a particular variety goes out of cultivation and is replaced by a different variety. Cultivators always prefer to change the varieties after a period, and more often this is necessitated by changes in trade requirements. It is particularly so where the rice area is concentrated as in the deltas where only a fraction of the produce is needed for local consumption and the balance has to be exported to other parts of the province where preferences for particular sorts may vary. Sometimes a variety loses popularity because of the fall in yield due to exhaustion of the soil as manuring the field is not a general practice. But even when they cease to be popular the strains once evolved have to be maintained in the breeding stations, and hence the large number of strains listed need not confuse anyone. To suit the varying conditions of soil, season and water facilities multiplicity of varieties is inevitable. Having too many types within a tract is, however, a disadvantage from other considerations such as milling and trade. A compromise has to be made between the two requirements. In the list of Madras strains given in Appendix III, certain distinctions have been made with regard to their comparative popularity with cultivators. Those underlined are the most popular and occupy extensive areas and those marked with an asterisk have ceased to be popular and not grown by cultivators except to a very limited extent.

Further work

A large number of improved varieties has been evolved, and it may be said that in Madras improved varieties suitable to the different rice tracts are already available. It would appear that further work must consist in intensifying the hybridisation programme so that in addition to increased yield the new varieties should have improved ancillary characters. Extra earliness, strong straw, freedom from shattering of grain, resistance to diseases, good response to improved cultural and manurial practices, suitability to special conditions as indifferent water supply and drought, etc., should be the special characters to go for in such programmes. Because of the facilities available, wide crosses, interspecific and interracial, could be undertaken. Study of rice genetics which was receiving considerable attention in earlier years appears to have received a setback in recent times.

BIHAR

With an area of nearly ten million acres under rice representing 60 per cent. of the cultivated area, and an average output of 2.8 million tons of rice, Bihar province contributes about 11 per cent. of the total rice production in India. There are three natural agricultural divisions into which the rice tract of the province can be separated :

(1) South Bihar comprising the low lying area, south of the river Ganges with heavy and moderately heavy clay soil types ; there are irrigation facilities in this area and the rice cultivation is concentrated here ;

(2) North Bihar which lies to the north of river Ganges, the soil is light alluvium with a good moisture retaining capacity ; the crop is dependent solely on rain and there is diversity in cropping, sugarcane, wheat and tobacco being grown in addition to rice ; and

(3) the terraced hilly area of Chota Nagpur comprising mostly of reddish gravelly soils, dependent upon the south-west monsoon rains for successful harvests ; rice is the chief crop here.

The soil, cropping and varieties in these three areas are distinct and there is no overlapping. The varieties doing well in South Bihar are not successful in North Bihar and *vice versa.*

Of the ten million acres, three millions are under irrigation either from Government canals or by privately owned inundated channels, tanks and wells. The acre yields are generally poor. In a large portion of the rice area in Chota Nagpur and in portions of North Bihar, rice is sown broadcast while the practice of transplanting is followed in places where better water facilities exist. Even in the better sorts of land, short duration varieties are preferred as these allow of *rabi* cereal, e.g. wheat or pulse, to follow rice. The rice varieties of Bihar may be grouped into two large divisions :

(1) the *aus* or the autumn-rices (June-July to September-October) including (a) the *ghora* of Chota Nagpur and (b) the *bhadoi* of Bihar proper, and (2) the *aman* or winter rices, early, medium and late mostly transplanted (June-July to October-November).

In the early years the rice work in the province was done at the Government Farms at Sabour in South Bihar, Sepaya in North Bihar and Kankee in Chota Nagpur. Most of the early research, which was under the control of Deputy Directors of Agriculture, was devoted to varietal trials and investigations on manurial problems. Rice strains and varieties from Bengal and the Central Provinces were introduced but they did not generally prove suitable to local conditions. Nevertheless, selection work in the local rices was also in progress, the intensity of such work depending upon the personal enthusiasm of the Deputy Director of Agriculture concerned and on the available time at his disposal. Earlier selection work in some of the important varieties on the farms had resulted in the production of strains like *Dahia, Kankee* Nos. 1 and 2, Cuttack Nos. 1 to 5. Though the post of Economic Botanist was created in 1929 it was only in 1932 with the financial aid from the Indian Council of Agricultural Research that it was possible to take up work on organised lines. A wholetime Rice Research Officer was put in charge of the rice work with headquarters at Sabour. Late Mr. Alam was the first Rice Research Officer so appointed and all the results, either breeding or genetical, reported in this publication were those obtained by him. It may be pointed out that the conditions of soil and climate at Sabour represent those of North Bihar and do not represent the heavy soils typical of South Bihar. Substations were opened at Kankee for Chota Nagpur, Gaya for South Bihar and Cuttack for Orissa and this last station was later handed over to the new Orissa province in 1937. The Indian Agricultural Research Institute at Pusa did some work on North Bihar rices during the last days of its life there.

Selection

Aman. Five thousand samples mostly in earheads were collected in the *aman* groups of varieties of different durations from all over the province and grown in single lines with 40 plants for each earhead. After rejecting the duplicates and segregating cultures, the initial number was reduced to two thousand and this large collection is being maintained at the stations of each tract. Some of these cultures though very similar to each other in most of their characters show differences in their yielding capacity suggesting the existence of distinct biotypes. All the selection work was, however, concentrated on fixing pure lines on the basis of morphological characters only and comparing them later for yield in replicated trials. Such yield trials conducted in the experimental stations comparing the isolations against the varieties already under distribution, gave a certain number of promising pure lines suitable for early, medium and late *aman* seasons. These pure lines were distributed to the cultivators in 1941 as improved varieties (*vide* Appendix III). Intensive selection in natural populations of an individual variety has hitherto not been attempted. As a result of the work of isolating pure lines from the varieties in North Bihar and their subsequent trial at Pusa, a late type, T.31 was recommended for distribution from the late Pusa Institute, Pusa.

Aus. Bhadoi rices (the short duration varieties common in Bihar) were taken up for study in 1938. The rices are all coarse and have red kernels. Attempts were made to get good types with white kernel from out of the collection and it was found that these fine white rices could not compete in yield with the red coarse rices common in the locality. Work at the Indian Agricultural Research Institute, Pusa, has resulted in the isolation of two promising types T. 18 and T. 124 in the early group. Two more lines 88 BK and 115 BK from Sabour are reported to have done well, and they are being grown by the cultivators of the tract.

Ghora rices. The cultivation of rices in Chota Nagpur is very precarious, owing firstly to the rush of water during the monsoon causing soil erosion, and later to drought, resulting from an early cessation of the monsoon. There are no facilities for irrigation and the rice crop suffers at its later stages. Hence, the demand here is for early, drought-resistant types, capable of growing under poor soil conditions. Work on these rices was started at Kankee substation in 1937. The work is in progress. The preliminary yield tests conducted in 1939 with some of the selections would appear to indicate that it is possible to get pure cultures with fine, white rice and at the same time giving good yields, a thing considered impossible in the beginning.

Hybridisation. Wild rices belonging to the species of *Oryza sativa* var. *spontanea* are troublesome weeds in the rice fields specially where broadcasting is practised causing a fair amount of loss, though not to the same extent as in the Central Provinces. Crosses were made in 1936 between a strongly pigmented variety poor in yield and rice quality, and some of the more prolific varieties available in the pure line collections. It is reported that it has been possible to select several cultures combining full purple colour in the entire foliage with medium fine grains and satisfactory yields.

What remains to be done

(1) The work so far done meets mainly the requirements of South Bihar. Even here intensive selection in the most important varieties of the tract should prove more useful than confining the trials to pure lines isolated mainly on morphological differences.

(2) Breeding special improved types for North Bihar has yet to be undertaken; the work done at the Pusa Institute cannot meet the requirements sufficiently.

(3) Intensive selection work on the important varieties of Chota Nagpur tract.

(4) Breeding of special types with non-lodging straw of medium and early duration by suitable hybridisation.

UNITED PROVINCES

Rice in the United Provinces occupies 7.1 million acres forming 20 per cent of the total cropped area, with an output of 1.85 million tons. The rice area of the province can be divided into three distinct regions :

(1) The high, mountainous region in the north west of the province with porous, gravelly soils and an abundant annual rainfall of 80 inches, the land being thrown into terraces.

(2) The flat fertile Gangetic alluvium lying in the centre and east of the province bounded by the rivers Gogra and Jumna, with soils containing varying proportions of clay and sand.

(3) The *tarai* region consisting of a strip of land varying in width and stretching along the northern boundary at the foot of the Himalayas with a rainfall of 40 to 50 inches enough for a rice crop ; the soils are clayey, rich in humus and retentive of moisture.

Nearly 70 per cent of the rice area in the province is broadcast and is mostly grown with early varieties ; the crop is interploughed later on if weeds are abundant. The practice of transplanting is confined more or less to late rices (*aghani* or *jorhan*) and is more in vogue in the eastern tracts where late rices are generally preferred. Except for the central portion between the Gogra and Jumna rivers and the area which has recently been brought under the Sarada canal, 90 per cent of the rice crop is dependent upon rainfall which is, however, generally sufficient.

Early varieties of rice which are coarse grained and generally broadcast. dominate the rice cultivation in many places and allow of a *rabi* pulse, linseed or cereal to follow them. The late transplanted rices are confined to the low level areas.

Selection. On the farms which were in existence at Atarra, Pratapgarh and Bareilly, work on rice consisted of a few trials of varieties introduced from other places and such of those which were better were being multiplied and distributed on a small scale. The Economic Botanist of the province was devoting most of his attention to other crops. In 1921 a start was made to collect samples of rice varieties all over the province and about 1,300 samples were collected and grown at Cawnpore, the headquarters of the Economic Botanist. The farm at Cawnpore, however, was not suitable for rice growing but the preliminary work was still done there and large field trials were later conducted at Dehradun and Tulsipur. Rice Research which formed part of the Economic Botanist's activities was separated in 1932, when financial assistance was secured from the Indian Council of Agricultural Research and put under the charge of another Economic Botanist (Sugarcane and Rice) with a whole time Research Staff at the Nagina Station Mr. R. L. Sethi was the first Economic Botanist (Sugarcane and Rice) to be appointed and most of the results reported here have followed out of his work.

The soil is light loam over the greater part of the Nagina station and suitable for cultivation of early rices. A portion of the station, however, possesses clay loams in which late varieties can also be grown. The heavy clay type of soil which is found in the important areas of the eastern rice tract is, however, not present. The main object of the grant made by the Indian Council of Agricultural Research was to expand and develop the work that was already being done by the Economic Botanist with special reference to the production of better quality, high yielding rices for the Sarada canal tract where low yielding, poor quality, broadcast rices were common before the introduction of canal irrigation. Selection work at Nagina resulted in the production of several improved strains (*vide* Appendix III). These are being tested against the local varieties in cultivators' fields. A survey of the rice tract, specially the eastern area, was undertaken in 1938 and the improved types produced elsewhere did not compare favourably with the local varieties which were best suited to the conditions.

Hybridisation. Evolution of strains resistant to rice bug (*Leptocorisa varicornis*). The early rices are generally very inferior in quality and are liable to attacks of rice bug, *Leptocorisa varicornis*. One of the problems on which the rice grower in the province needs help is to stop or reduce the loss in the early crops due to the ravages of the rice bug. In certain years the damage to the crop is very extensive. The insect is mainly active from the middle of August to the middle of October and disappears with the beginning of cold weather. Any variety that flowers during this period is subject to the insect attack. The cultivators prefer to grow an early rice because it enables them to follow it with a *rabi crop*. Besides, the rainfall and irrigation not being sufficient, long duration varieties cannot be raised successfully. The varieties usually grown are very early and coarse and have red kernel. One of them is called *Sathi* (meaning 60 days crop), short-growing, and very poor in yield; but by virtue of its enclosed or *sheathed* ear, it escapes the damage from the rice bug as the insect cannot reach the grain in the milk stage. This natural protective device was taken advantage of to breed by hybridisation an early, good quality rice, with the *sheathed* ear to enable it to escape the damage from the *gundhi* insect. A number of crosses was made as early as 1930 between the *Sathi* variety (T.131) and four heavy yielding types of different durations (T.1, T.3, T.7 and T.12) with good quality rice. The hybrids were intensively studied up to the twelfth generation to get homozygous types combining the enclosed ear with other desirable characters. Pure types with desired combinations of enclosed ear and better grain qualities have been isolated. The selections with partially enclosed ears while being not so early as the *Sathi* parent give 20 to 25 per cent more yield than the same but they do not, however, approach the normal parent in yield. The enclosed ear and poor yield are more or less associated. Nevertheless, the partially enclosed selections were found to show resistance to the rice bug. A drawback in these selections was, however, the difficulty of threshing the grain. Backcrosses have been made between them and the high yielding, 'normal' ear parent to improve the yield and the results are awaited.

Though these crosses have not produced results to the degree desired, the attempt to breed by hybridisation types resistant to rice bug have a special interest to the scientists as it furnishes an example of overcoming insect damage by breeding methods.

Other economic crosses. In 1937 a number of other crosses between suitable parents was effected with the following objects :

(i) to evolve very early, good yielding, fine quality strains using a few exotic varieties from China, and Texas (U.S.A.) as parents ;

(ii) to breed early, scented types to resemble the commercial variety of *Basmati* so that they can be grown over large areas (T. 3 × T.2), (T. 3 × T.1) ;

(iii) to combine awning with good yield suitable for the wild pig infested areas along the borders of mountains (T.7 × T.43), (T.1 × T.43) ;

In the above crosses selections have been made with the desirable combinations and await yield comparison against the local types.

(iv) to evolve high yielding late types for the East Gangetic alluvium ; a fixed hybrid No. 108 is said to meet the requirements and is being distributed, and

(v) to combine *Basmati* quality in awned rices. This cross is in early stages of study.

Deep water rice. A demand exists for deep water rices along the submersible areas in the *tarai* region for which varieties from Bengal reputed to stand submersion, were first tried but were found unsuitable to the local conditions. There is a local variety called *Jassaria* which is, however, not satisfactory in yield. Work for this area has not yet been undertaken for want of facilities.

What remains to be done

(1) The eastern portion of the province, containing large areas of non-irrigated rice but with sufficient rainfall, possesses a markedly different set of soil and climatic conditions from that obtaining in the Western areas. A small substation in charge of a junior assistant has been just opened at Gorakhpur with 10.0 acres under rice ; but it would appear that none of the important varieties of this area has yet been taken up for selection work. It is reported that some early strains, N.22, N. 27, N.32, A.64 and T.136 evolved at Nagina are somewhat useful to replace the popular local early varieties *Sarva* and *Deola* grown over fairly large areas. Evolution of high yielding short duration strains from the local varieties which are the ones best adapted to the tract will have to be taken up.

(2) Improving the commercial *Basmati* and *Hansraj* varieties by selection within them after collecting samples extensively from the tracts in which they are grown.

(3) Improving the grain shattering character of fragrant varieties.

(4) Obtaining of suitable high yielding varieties for the *Tarai* region.

CENTRAL PROVINCES AND BERAR

Rice in Central Provinces and Berar is exclusively a monsoon crop. It has an average area of 5.9 million acres and an output of 1.5 million tons. The principal rice area may be divided into three distinct zones :

(1) the eastern tract comprising the districts of Drug, Raipur and Bilaspur in the Chhattisgarh division ; the bulk of rice production is in this tract ; it is mostly broadcast and depends for its success on a well distributed and adequate rainfall ;

(2) Wain-ganga basin in the South comprising the districts of Balaghat and Chanda ; this area has irrigation facilities and 70 per cent of the area is transplanted ; and

(3) the northern portion including Seoni, Mandla and Jubbulpore districts ; the rice area here is small and is confined to places which command irrigation supplies from tanks ; early varieties only can be grown in this area.

The rice soils of the Chhattisgarh division are of two kinds ; (1) *matasi*, a fine grained yellow loam which is considered ideal for a single crop of rice, and (2) *dorsa* or *dorasa* (literally meaning two kinds) a mixture of the light *matasi* and the black heavy *kankar* clays, *dark* grey in colour supporting a *rabi* crop of pulse after rice. The soils of the Wain-ganga valley are crystalline in origin and resemble those of Chhattisgarh but are slightly heavier in texture than them. The soils in the northern area are mostly of the *dorsa* type. Nearly seventy five per cent of the area in the province is broadcast either in puddle or dry, and in the more favourable localities of the Chhattisgarh division with facilities for irrigation or enjoying heavy rains, there is the practice of *biasi* or ploughing the crop when about six weeks old, with the triple object of weeding, thinning and stimulating the growth of rice. A small area in the hilly districts is drilled after clearing the jungle by burning the bushes and shrubs and spreading the ashes. Since a large part of the area is dependent upon the activity of the south-west monsoon which wanes generally by the end of September, early varieties of rice are more common. Medium and late rices are confined to those areas where there are facilities for irrigation. Wherever possible a *rabi* crop of linseed or wheat or a pulse follows rice.

Early work on rice

The Raipur station, one of the oldest of agricultural stations dealing with rice, was opened in 1903. The farm represents all the types of soil and enjoys a good rainfall of 50 inches which generally ceases by the middle of October. Most of the early experiments at this and other stations which were under the control of the Deputy Directors of Agriculture were confined to the study of the effects of different systems of cultivation and manuring on yield. The Economic Botanist with his headquarters at Nagpur was devoting only part of his time towards the collection of rice varieties and fixing pure lines from the mixtures of types in the several varieties. The fixed types were being sent later to the Raipur and Jubbulpore farms for being compared against the local varieties. With the limited time which the Economic Botanist, Dr. Graham could devote to rice, some progress in the evolution of better sorts of rice, e.g. *Parewa* 143, *Bhondu No*. 11, *G*.13, *EB*. 17, was achieved. When these were found to be better yielding than the local varieties, a net work of rice seed farms was organised and pure seed (free from wild rice mixtures) was distributed from them. After the retirement of Dr. Graham in 1915, the work on rice received a setback. Between 1915—24 the work rested largely with the Deputy Director of the eastern circle. Inspite of several handicaps, the trial of several varieties from out of the collections already available gave certain useful and high yielding varieties which were first grown in the stations and later distributed to cultivators.

With the appointment of the Second Economic Botanist, Mr. Mahta in 1924, a fresh stimulus was given to the work on rice. The first step consisted of making a collection of varieties for study. Selection work was next concentrated on a few important varieties. Three strains, i.e. *Bhatagurmatia, Parewa* 14, *Luchai* 7, from the important local varieties were thus isolated. Dacca No. 1 which had been introduced from Bengal was also found to do well.

In addition to the improvement of the local varieties of rice, there was the pressing problem of evolving a variety which could easily be distinguished from the wild rice, a very common weed in the Central Provinces. The eradication of wild rice assumes great importance in areas where rice is grown as a broadcast crop with the result that there is no possibility to keep the wild rice under control. The wild rice, *O. sativa* var. *spontanea,* locally known as *Kharga* occurs as a pernicious weed in the rice fields and owing to its very close resemblance to the cultivated rice in all its vegetative characters escapes the notice of the cultivator at the time of weeding. Owing to the extreme shattering nature of the grain even when it is half ripe, no seed can be collected in the wild rice. An estimate of the incidence of wild rice from a survey conducted over 1350 fields revealed that it varied from 3 to 16 per cent. ; even taking the minimum figure of three per cent., the annual loss would work out to about 2 million rupees over the 3½ million acres of broadcast area. This was sought to be remedied by resorting to hybridising the common varieties '*Bhondu*' and *Budhiabako* with the variety '*Parewa*' which though low yielding had coloured auricles. Selection of segregates from the progeny with the *Bhondu* and *Budhiabako* characters but with coloured auricles as distinct from the wild rice which has green auricles should, it was considered, minimise the trouble. Two selections, crosses 116, and 19, were thus evolved, and these have been under distribution for some time. This did not, however, obviate the trouble altogether as the F_1 hybrids with wild rice cannot be distinguished from the cultivated type owing to the dominant nature of the coloured auricle.

Agricultural Station, Raipur

The work of rice breeding at the Raipur station was reorganised in 1932 as part of the co-ordinated scheme of rice investigation in India under the aegis of the Indian Council of Agricultural Research with a full time Research Officer in the person of Mr. Dave. The Rice Research Officer shifted his headquarters to Raipur, and the two substations at Waraseoni and Adhartal, situated in the Wainganga valley and the northern tract respectively were utilised for carrying out trials of pure lines evolved at Raipur. Some valuable varieties have come out of Dave's work.

The breeding work in rice at Raipur consisted of the continuation of the older investigations, viz., systematic study of varieties for isolating pure lines from the existing mixtures ; varietal trials and intensive selection in the best varieties ; improvement of the fine varieties by single plant selection ; and breeding new types distinguishable from the wild rice in early, medium and late groups.

Varietal trials. An extensive trial of existing pure lines from varieties was first undertaken to determine the best out of them. Three hundred and fifty six varieties covering early, medium and late groups were tried on the Raipur farm with the existing departmental strains as controls in randomised blocks. As a result of three year's trials, it was found that in the early group R3, a pure line from *Sultugurumatia* was the most prolific and could replace the standard variety *Bhata gurumatia* in vogue ; it was also higher yielding than the medium duration strain *Surmatia* (*vide* Appendix III). Amongst the medium ripening varieties, it was noticed that none of the pure lines could beat cross 116. Amongst the good quality medium duration rices, R6—*Budhiabako* and *cross* 19 were the most promising. In the late group the pure line R7 from *Ajan* had given an average increased yield of 24 per cent over *Gurumatia*, the most popular variety of Chhattisgarh division ; R8, a pure line from *Benisar* had proved superior to Luchai strain already under cultivation in point of yield, milling quality and fineness of kernel.

Similar trials were carried out at the Waraseoni substation in the Wainganga valley with 260 pure lines. The results showed that a pure line *Nungi* (R2) and *Sultugurumatia* (R3) were superior to the early varieties of *Chipda* and *Ruibata* commonly grown. Cross 116 and *Budhiabako* (R6) were superior to the medium ripening local varieties *Selo* and *Samudrasok*. *Ajan* (R7) and *Benisar* (R8) were found superior in this tract to the late varieties of *Pisso, Haradgundi* and *Luchai*. Out of the trials with one hundred and eighty seven pure lines at the Adhartal farm in the north of the province, *Sultugurumatia* (R3) and cross 116 were found superior to the existing local varieties of similar duration. Mr. Dave believes that further selection work in those varieties, the pure lines of which have already proved superior, is not likely to produce better results.

Fine varieties. The Central Provinces is noted for its large number of fine scented varieties. The varieties are, however, very badly mixed up and to find a profitable market for them they have to be purified. Selection work was, therefore, started simultaneously in five of the scented varieties in 1933 with hundred lines in each of them. Eight uniform ripening strains, R.10 to R.17 (*vide* Appendix III), which were also higher yielding than the corresponding mixed varieties, were evolved and are now under distribution.

Hybrids for wild rice infested areas. As has already been said the occurrence of wild rice is a serious problem in the Chhattisgarh area. Amongst the cultivated types there exists a variety called *Nagkesar* which is deeply pigmented all over, and the purple lamina of this variety is recessive to the green one. Hybridisation was, therefore, undertaken in 1934 between this variety *Nagkesar* and three varieties, No. 17, *Bhondu* and *Luchai* representing early, medium and late groups. By 1939 it was possible to select pure breeding segregates, named crosses 1, 2 and 5, resembling the better yielding parents of the three groups in all respects except in the colour of the stem and leaf which is purple as in the *Nagkesar* parent. It is now quite easy to distinguish the wild type and eradicate the same completely in the course of one or two years if sufficient attention is paid to roguing. These selections were tested in 26 centres in the Raipur, Bilaspur and Drug districts for three seasons and the yields are reported to have been satisfactory approaching the green parents, though in one case the green parent was found to be superior.

To further improve the yields of these hybrids they were backcrossed to the green parent in 1940 and it is only a question of time to get hybrids with coloured lamina and stems with as high yields as the respective green parents.

Other economic crosses. The following sets of crosses are at different stages of study and progenies with the desired combinations are being selected as the study progresses :

(i) *Luchai* × each of *Ludako, Budhiabako, Chattri, Chinnor,* Cross 22 and *Ajan,* to evolve varieties with good stiff straw and less of grain shattering ; *Luchai* is a superior variety with stiff and rigid straw.

(ii) R.10 *Chhattri* × R.2 *Nungi,* to evolve early ripening, fine scented strains ;

(iii) R.10 *Chhattri* × R.6 *Budhiabako,* to improve the yield of scented variety *Chhattri ;*

(iv) R.2 *Nungi* × *Blue rose,* Cross 22 × *Blue rose, Gurumatia* × *Blue rose ;* to evolve strains with bold translucent grain like *Blue rose* with different durations and

(v) R.2 *Nungi* × No. 13 *Malchi* to evolve early heavy yielding strains which will ripen off by the end of September for the northern area.

Further work to be done

(1) Intensive study and isolation of strains in the varieties which are found to be the most prolific by collection of samples from several localities where these are extensively grown.

(2) Survey of the rice area in the northern portion of the province and isolation of high yielding strains for this tract.

(3) The improvement in yield of the purple-leaved hybrids by backcrossing. These crosses have already been made and the progenies are now in the F_3 stage.

(4) Improvement in yield of the commercial variety *Budhiabako ;* crosses are already under way.

(5) Production of good yielding, early rice with bold translucent kernels. Crosses with *Blue rose* are now in F_5 stage. But the occurrence of a good amount of sterility in the progenies appears to preclude the possibility of realising the combinations aimed at. Local varieties with grain like *Blue rose* may be tried as parents.

(6) Improvement of the yield of the fine, scented varieties by hybridisation ; some of the cross progenies are now in F_6 stage.

ASSAM

In Assam, the agricultural conditions of which resemble those of a greater portion of East Bengal, rice is the staple crop with an area of about 5 million acres producing 1.9 million tons. The rice area, confined to the two valleys of the Brahmaputra and Surma rivers, comprises of five agricultural classes of rice as in Bengal :

(1) The *aus* or summer rice either sown broadcast from April to May and reaped in July and August or transplanted in June and harvested in September to October ;

(2) the *sail,* or winter rice transplanted in the months of June to July and harvested in December to January ;

(3) the *asra* or deep water rices which can withstand water depths between three and six feet ; broadcast generally in May to June and harvested by December ;

(4) the *aman* or the typical rank growing deep water rices with long stems, broadcast in the month of March on marshy lands which are subject to heavy floods during the monsoon and harvested in November ; and

(5) the *boro* or the spring rices transplanted during December in the low marshy areas as floods recede and irrigated from *bhils* or natural depressions which retain water throughout the year.

Glutinous rices which occur in all the above groups are esteemed highly by the Assamese. Besides these, there are the hill or *jhum* rice varieties which are cultivated on the hill slopes after deforestation and usually as a mixture with a number of other crops. Jute preceding rice is a common feature in the more secure areas. Growing of *rabi* crops is almost unknown in Assam.

Work on the first three groups of rice is being done at Karimganj station in the Surma valley opened in 1914 and at Titabar farm in Assam valley opened in 1924. The work first consisted of pure line selection and later hybridisation was also undertaken. The Economic Botanist, Dr. S. K. Mitra, was in charge of the rice work in the early years and has been responsible for the improved strains evolved and also for valuable contributions to the genetics of rice.

1. Karimganj and Titabar Farms

Pure line selection. The selection methods followed in Assam were confined to the selection of the best variety in each group of rices. The first step was a collection of samples from different places of the province followed by isolation of pure lines from them, based upon morphological characters. A series of varietal tests had been continued year after year in each of the three classes of rice. When a pure line gave high yields consistently over a three to five year period, it was recommended to the cultivators. Following this line of work a number of pure lines from the three groups has been issued for general cultivation (*vide* Appendix III).

Hybridisation. Following fixation of pure lines from varieties, hybridisation work was commenced in 1926 at both these farms to combine the good qualities of two or more parents and by 1938 one hybrid in each of *aus* and *sail* was recommended for distribution. Further hybridisation work is in progress and promising material is reported to be available. About two thousand hybrid cultures were under study in 1940.

2. Habiganj Farm

Work on *aman* and *boro* rices was started with the opening of a station at Habiganj in 1934 with funds provided by the Indian Council of Agricultural Research. Mr. Majid was the first officer appointed to run this station and most of the results reported from this station have arisen from his work. It may be mentioned here that this station is started in an area subject to heavy floods in June and July with the result that the work is carried out at great risks and difficulties. The two problems that await solution at this station are (1) the evolution of strains in the *aman* varieties which can stand complete submergence in water, i.e. which can resist the uprooting action of rushing water during the monsoon and which can grow quickly to keep pace with the rise in water level later, and (2) the evolution of *boro* strains which can face drought successfully, specially during the later part of their life cycle, when water in the natural depressions, on which they depend for water supply, dry up. In the latter case earliness without loss in yield is also a *desideratum* to escape the damage by hail storms which may occur in March-April.

Pure line selections

Deep water rices. As observations have to be made in water varying from 10 to 20 feet deep, special devices had to be improvised to study the rices under such abnormal conditions. An artificial tank with facilities to grow rices in different depths of water was first tried but it had to be abandoned as it did not represent the typical conditions obtaining in deep water areas. Later, an iron frame which could be worked by screw-gears was improvised. Plants grown in special tin containers were attached to the frame work and these containers could be raised or lowered to keep them under desired depths of water. The observations on varieties grown under such conditions were confined to growth rate records at critical periods of water rise and duration. Arduous as the work had been, 473 cultures were isolated from the local varieties along with records of morphological characters. A large number of varietal tests with the most promising ones out of them was conducted for two years. Four types of different durations, *aman* 1, 2, 3 and 4 (*vide* Appendix III) were isolated and recommended for distribution. Trials with further material have shown the high yielding nature of some of the cultures, viz., 129, 49-2, 249, 268, 48-14, 29-1, 51-5-5, 185 and 133. From these cultures it is hoped that it may be possible to isolate strains with higher yields than those already under distribution.

The findings of certain agronomic investigations regarding deep water rices are recorded below : (1) the height to which a plant grows is no criterion for its flood resistance ; (2) during the period when rise of water level is gradual, the height of the plant above water level appears to be different for different varieties ; (3) some types can stand a longer period of submersion than others ; (4) the age of plants at the time floods occur has a profound influence on subsequent growth under water. In the case of early varieties six to eight weeks is the optimum age to respond to water rise, and (5) the presence of sufficient moisture at the time of sowing and sufficient interval, preferably six weeks, between sowing and advent of flood are indispensable for a successful *aman* crop, i.e. sowing should be done before the second week of May.

Boro rices. Four hundred pure lines were isolated by 1939 from the several varieties varying in duration from 115 to 131 days. From a study of these rices it was found that they fell into well defined groups with special characteristics for which they were in demand. For example, the *boro* group was found to do well in the higher slopes requiring less water while the *tupa boro* group and the *sail boro* group were suitable for lower levels of water. The several pure lines isolated from each group were compared in extensive field tests on the station, and based on these tests, three pure lines named as Hbj. *bora* 1, 2, and 3 were recommended as the best among them (*vide* Appendix III). Further field trials are under way to evolve higher yielding strains than the ones already recommended.

Hybridisation

(i) To improve the quality of *aman* rices combined with their capacity to resist flood, a few crosses were tried for the first time in 1941 to 1942 between typical *amans* and between *amans* and *Latisail*, a sturdy winter rice with a heavy yield.

(ii) The *boros* are as a class generally coarse with red kernel and it has been found that these are the ones most suited for growing in the spring season. With a view to secure a better quality type retaining its adaptability for growing in the *boro* season, a series of crosses were made between desirable parents as shown below :

(1) *Aus* × *Boro,* (2) *Rata* × *Prasadbhog,* (3) *Boro* (early) × *Tupa Boro* (awned high yielding) and *Bashful* (awnless white kernel) and (4) *Tupa* × *Bashful.*

These crosses are at various stages of study and it is too early to report on them.

Further work to be done

(1) Of the three strains that have been released, only one Hbj. *aman* 3 is resistant to some extent to high floods ; it is necessary to produce strains which are even more resistant to flood than this ;

(2) to determine flood resistance and to devise methods to study flood resistance on a larger scale ;

(3) histological differences, if any, amongst flood resistant varieties ; and

(4) evolution of early maturing, better quality *boro* rices with high yield.

ORISSA

Orissa province has an area of about 5 million acres and an output of 1.3 million tons of rice. Rice occupies 80 per cent of the total cultivated area and small as the province is, the soil and climatic conditions over which rice is grown very considerably. The following are the distinct rice areas in the province.

(1) the Mahanadi and Rishikulya basins with an adequate rainfall and a good system of irrigation;

(2) the low lying, submersible areas with a precarious crop in the main season followed by a spring rice called *dalua;*

(3) the coastal belt liable to inundation in the summer season by sea water and

(4) the uneven and hilly zone comprising the Jeypore Zamindari and Sambalpur district.

The diversity of soil and climatic conditions had given rise to an abundance of ecological types. The rices of the province can be divided into three classes :

(1) *The aus or autumn rices,* consisting of the *beali* and *laghu* groups;

(2) the *sarad, aman* or winter rices with differing durations and

(3) the *boro, dalua* or spring rices.

The rice soils of the province vary in texture. Rich and friable loams particularly suitable for rice, characterise the Mahanadi and Rishikulya areas; the submersible tract is darker coloured stiff clay, fairly rich, but in this, the crop is usually precarious; the coastal tract comprises mostly of saline lands with low yields and poor laterite soils are met with in the higher regions.

The majority of the areas is cropped from June and July and depending upon the conditions of the soil and water supply, either early or late duration rices are raised. In those areas which are subject to periodical inundations, where either a main crop is precarious or cannot be grown, *dalua* is sown immediately after the floods recede from December and harvested in March and April. The early *bealis* and *laghus* are mostly broadcast and *sarad* rices in the low level areas are either transplanted or broadcast. Of the five million acres, 0.8 million is classed as irrigated either from Government canals or private sources. The work on rice is carried on at three stations, Cuttack, Berhampur and Jeypore.

1. Rice Research Station, Cuttack

Prior to the formation of Orissa province in 1936, the major portion of the province was included in Bihar and another small portion in the Madras Presidency. Earlier work on the rices of Orissa was under the charge of the Deputy Director of Agriculture, Orissa range of Bihar, and was conducted at the Cuttack station. This was directed mainly towards the solution of cultural and manurial problems. By studying a large number of varieties based on a series of varietal comparisons, it was possible to recommend to cultivators even as early as 1918 three varieties, Cuttack Nos. 1, 2 and 3 in the early, medium and late durations respectively. A strain Cuttack No. 5 with strong straw that does not lodge and resists the action of floods to a moderate extent was isolated later from Cuttack No. 3, in all probability a natural cross occurring in it. Further work included testing of varieties against the strains already evolved but the work did not meet with any success.

With the appointment of a Rice Research Officer for Bihar in 1932 with funds provided by the Indian Council of Agricultural Research, a portion of the Cuttack farm was set apart for a systematic study of the several rice problems of the Orissa range. The Rice Research Officer, Bihar, was controlling the rice research in Orissa also and with the formation of the new province in 1936 the work was taken over by Mr. Dixit, the provincial Paddy Specialist.

Beali and laghu groups. These occupy a million acres and are all short duration rices. Work on these rices was started in 1937-38 with a collection of about a hundred local varieties and pure lines based on morphological characters were isolated from these. Based on size of grain and colour of kernel four classes can be distinguished in these groups, the coarse grain with red kernel being the predominant class. From a study of the field characters and yield differences, pure lines which are higher yielding than the local varieties are undergoing further trials in large scale tests. One strain 116A has been issued for large scale multiplication.

Sarad or winter rices. These are usually broadcast in June and July and to a limited extent transplanted from nurseries. They vary in duration, the harvests coming on from 15th October to 15th January. These are divided into three groups early, medium and late to suit the different situations of water availability. A large number of pure lines from 250 established varieties was under study and yield trials with the best of them gave a few recording ten to fifteen per cent higher yield over the corresponding control in different classes (*vide* Appendix III).

Dalua or boro rices. This is a comparatively small group grown on about 30,000 acres. Following the same procedure of collection of varieties, isolation of pure lines and a series of trials with them, some high yielding pure lines were recommended for growing by the cultivators. In certain seasons when the floods are severe, more area will be available for growing this group of rices but the difficulties of seed supply are always present. It is a common feature of the monsoon areas that the seed of the previous *dalua* crop cannot be carried over to the next under ordinary conditions of storage, and the cultivator is forced to grow a small seed plot in the main season for the *dalua* crop immediately following. Thus the supply of *dalua* seed is always limited. This drawback was sought to be remedied by finding but if any short duration *beali* rice would grow in *dalua* season and attempts so far have not proved fruitful. But it is reported that some early varieties growing in the monsoon on the hill slopes in Jeypore agency showed some promise when grown in the *dalua* season at Cuttack.

Fine varieties. There is some demand from outside the province, specially in Madras and Bengal, for a fine rice *Sita salo* growing in Orissa. Trials of a large number of fine rices have shown the suitability of three pure lines all similar in size and shape of grain, *viz.*, T.608 for high level, T.812 for medium and T.90 for low level lands.

Flood resistant varieties. The determination of suitable types for the low lying lands subject to submersion is beset with several difficulties, such as, an early onset of the flood and mechanical washing away of the young plants and a possible continuity of floods over long periods. The submersible areas of this tract differ from those of Assam or Bengal in that, in Orissa, the floods are intermittent while in Assam and Bengal the water keeps on rising continuously. The varieties grown locally are not generally resistant to floods. Therefore the production of a flood resistant variety was undertaken in a temporary farm in Kujang near Cuttack. A number of varieties was tried and a late maturing type which can stand complete submersion up to a fortnight was obtained. Selection work for flood resistance was later intensified at the Cuttack station to supplement the work in Kujang. While varieties were put under natural conditions at Kujang they were subjected to similar conditions of submersion by artificial means at Cuttack. A survey of the flooded tracts was also carried out in 1938 and on the principle of survival of the fittest, stray plants which were found surviving in rice fields where the whole crop had perished were selected. All these selections have been kept under observation and a number of strains has been evolved which are said to stand complete submersion even up to three weeks; of these F.R. types 13-A and 43-B deserve special mention.

Salt resistant rices. Another special feature of the rice tract in the province is the presence of fairly extensive areas along the coastal belt liable to inundation from sea during summer tide. Periodical cyclones also bring about the same results making these soils highly saline. These areas, therefore, require varieties that will resist salinity. Thirty local samples in these areas and also eighteen varieties from other provinces reported to be saline-resistant were collected and pure lines based upon morphological characters were evolved from them. These were compared against the strain, Kujang No. 2, already issued by the Department. Six pure lines were said to be quite satisfactory and of these S.R. type 26 B, which resembles the *Patnai* rice of Bengal has been found to be the best and is being recommended for large scale growing.

Hybridisation. Though no definite hybridisation work has been in progress for economic ends, a number of natural hybrids found occurring in a fine rice variety called *Hansraj*, has been under study and some of the progenies are reported to combine good tillering, bunched nature of earhead and fineness of grain.

This research station has, since 1946, been taken over by the Union Government, expanded and a Central Rice Research Institute established with technical staff and laboratories. All aspects of fundamental research in rice are being tackled here from the all-India point of view.

2. Rice Research Station, Berhampur

The genesis of this station has already been referred to under Madras. It was started by Madras Government in 1932 as a temporary station for five years and financed by the Indian Council of Agricultural Research. It was handed over to the newly formed province of Orissa in 1937 as a going concern.

Selection in local varieties. During this period of five years two strains in each of the five most important rice varieties of the tract were evolved. Subsequent trials in the cultivators' fields had shown the superiority, particularly of strains Bam. 1, 3 and 5 in *Boroponko, Bayyahunda* and *Ratnachudi* varieties respectively and they are becoming increasingly popular with the cultivator.

This tract abounds in a large number of fine varieties. Selection work was begun in a few of them and they were at different stages of study when the station was handed over to the Orissa province. Later work had shown the superiority of selections in two varieties.

There is a demand for short duration varieties in high level areas of the irrigated tracts and two varieties, *Nyayapusannam* and *Yerrakondangi*, were taken up for intensive selection work by the Madras Government in 1934. A strain in each of them was found to do well and these are now being multiplied for distribution to cultivators.

Hybridisation. In addition to selection, hybridisation work was also started by the Madras Department and a number of hybrid progenies at various stages of study was handed over to this station in 1937. Later trials of these by Orissa Department have given promising results.

3. Jeypore Substation

To serve the Agency area, a substation was opened at Jeypore in 1938 under the patronage of the Maharaja of Jeypore who kindly donated the necessary land and part of the finance for running the station. Preliminary work on collection of varieties and comparisons of strains already evolved at other stations in the province is under way. The material on hand is said to be promising and it is learnt that five promising strains, J1 to J5, have been isolated.

What remains to be done

(1) Evolution of suitable strains for :

(a) Tracts subject to occasional floods which submerge the crop for a period of 10 to 15 days.

(b) *Dalua* or *pat-lands* submerged for a considerable part of the year.

(c) Evolution of very early strains in the *beali* (autumn rice) group ; there is great scarcity in the early part of the season particularly with the poorer classes of people.

(2) Testing out the results of physiological investigations under field conditions.

(3) Hybridisation work to meet particular requirements of the tract.

BOMBAY

Though the province produces only 0.8 million tons of rice on an area of nearly two million acres, the rice crop nevertheless, covers a wide range of soil and climatic conditions extending from one end of the province to the other. Its cultivation is mainly confined to the narrow strip of land between the sea and the Western Ghats with a variable rainfall of 60 to 200 inches. The rice area may be divided into the following specific regions each of which has a particular class of rice of its own :

(1) North Konkan with a rainfall varying from 75 to 150 inches where the soils are blackish and heavy. The tract grows finer type of rice;

(2) South Konkan tract where the soils are usually gravelly and where rainfall is heavier: here the coarser rice with white kernel predominates;

(3) the southernmost taluks of South Konkan and below the Ghat in North Kanara is a tract predominant for rices with red kernels;

(4) the *Mallad* area comprising parts of Dharwar, Belgaum and a portion of North Kanara with low rainfall where rice is very coarse and white kernelled; and

(5) the *Maval* tract.—The eastern strip of the Ghat where rainfall is low and where scented rice predominates.

In the first two tracts, rice is mostly transplanted whereas in the *Mallad* area, it is mostly drilled and the cultivation is carried on with the help of a large number of ingenious devices for use at different stages of the crop. One peculiar feature in the agronomy of the transplanted rice is the *rab* system of raising nurseries which gives a healthy seedling growth especially where rainfall is heavy as in the Konkan. The method consists of burning cow-dung, thin loppings of certain trees, dried grass, etc., on the seed bed before sowing of rice. Experiments have shown that about 75 per cent. of the beneficial effect is due to the heating of the surface soil and about 25 per cent. only to the ashes which are added to the nursery. As most of the rice area is confined to the villages with different levels, varieties differing in maturing period are a necessity even in the same zone.

The early work in rice in the province consisted of agronomic experiments for finding out a suitable substitute for *rab*, and investigations on cultural details. A post of a plant breeder was created in 1917 for the improvement of rice, wheat and cotton, and Mr. H. M. Chibber occupied it till his death in 1920. Single plant selection work in the *Kolamba*, the most important group, was started in 1919 on sound lines. He was succeeded by Mr. Bhide who continued the work on the same lines and was succeeded in turn by Dr. B. S. Kadam in 1930. All the later results, both breeding and genetical, have come as a result of Kadam's work. His contributions to the genetics of rice in recent years deserve special mention.

Selection

1. Karjat Farm

In 1930 the headquarters of the Plant Breeding Expert, since changed into Crop Botanist to Government of Bombay, was transferred to the experimental station at Karjat. The important material handled on the station consisted of the famous *Kolamba*, the fine *Zinya*, early varieties of *Kada* and *Jirbuti* and a host of others. As a result of intensive studies in the field and in the laboratory in the *Kolamba* group, early, mid-late and late strains were obtained to suit the different levels of land. The strains are characterised by moderate tillering but with almost all fertile tillers, not too much of vegetative growth, reduced amount of sterility, bunched earheads and fine grains. Since the original selections made in the *Zinya, Kada* and *Jirbuti* did not sufficiently represent the range of available material in the tract fresh samples were collected again. In all the varieties improved strains are now available.

2. Ratnagiri Farm

Experiments had shown that the high yielding fine grained strains of *Kolamba* bred at Karjat were not suitable to South Konkan with a heavier rainfall and where the soil conditions differ very widely from the coast to the Western Ghats. On account of these differences, a large number of varieties is grown. *Patni* and *Kudai* are common amongst the early varieties, *Panvel, Bhadas* and *Waksal* among the mid-lates and *Varangal* among the late ones. Selection work was undertaken in these varieties and a strain in each of these was fixed for distribution. These strains are all white grained, uniform in maturity and they yield 10 to 15 per cent. more than the corresponding local varieties.

3. Kumta Farm

In the south of the province. the conditions are somewhat different from the north, the soils being lateritic and the rainfall heavier. Rice breeding work was taken up at Kumta in 1928. The improvement of the important local varieties of *Jaddu, Maskaty* and *Halga* engaged the attention of the staff. Good strains from each of them were available by the end of 1934. Certain areas of this tract are subject to floods during the monsoon and selection from variety known as *Kagga*, fairly resistant to floods, was undertaken.

4. Mugad Station

The rainfall in the *Mallad* tract being limited to about 40 inches, this area has cultural practices and also varieties entirely different from the other rice areas. Genetic improvement of rice varieties of this zone was started in 1923. Three strains, early, mid-late and late, from each of the varieties *Mugad* and *Antarsal*, to suit the different levels of fields common in the tract have been evolved. The *Antarsal* has anthocyan pigment in its vegetative parts and is generally alternated with *Mugad* so as to facilitate roguing of the wild rice mixture early in the seedling stage. Selection work in another early variety *Dodagya* was also started towards end of 1938. An improved strain from this variety is now in the process of distribution.

Hybridisation. The defects in the *Kolamba* strain, namely, a pronounced degree of sterility, a tendency to lodge and grain shattering were sought to be remedied by hybridisation but the attempts were not entirely successful. Tillering, heavy yield and fineness of grain never went together. It was however possible to combine earliness and fineness and pretty good yield, and one hybrid strain, K-540 now known as *Chanchala*, has been found to be very superior (Plate VIII). Hybridisation was again pursued using the *Bhadas* strain, which is noted for its stiff straw, less shattering though coarse grained, as one of the parents and it was found that it was not possible to combine the high yield and fine grain size of the *Kolamba* with the strong straw and less shattering character of *Bhadas*, the difficulties being genetic. However, better yielding *Bhadas* strains were evolved. Recently a new strain of hybrid origin, Z-31, combining earliness and high yield of *Chanchala* and translucent slender grain of an improved *Zinya* strain, Z-149, has been evolved.

At Mugad and Kumpta stations various crosses have been made to improve the local types and they are under study.

Work on special types

Salt resistant rices. In Konkan there are some areas with a net work of creeks running right through the country which remain flooded over with salt water at high tides, receiving 100 inches of rainfall in the south west monsoon. After raising embankments upto the height of water that would be received at high tide, these are cultivated with a special variety called *Rata*, with a coarse, red kernel and which resists a certain amount of salinity. Improvement of this variety is in progress.

Swampy areas. In the North Kanara district in some areas water stagnates up to three feet for more than ten months in the year except April and May. These are cultivated from December, planted in February and harvested in November. A coarse, tall growing variety with heavy tillering and large ears called *Heggebhatta*, is generally cultivated and it awaits improvement.

SIND

In Sind which receives less than ten inches of annual rainfall and which is characterised by the severest dry spells, rice occupies a large area, 1.3 million acres (all irrigated by the Indus canals). The area is equally divided in the *barrage* and *non-barrage* tracts the former having canal supply from May to middle of October and the latter from June to September. The soils of Sind are alluvial in origin, deep and varied in character. The maximum water holding capacity is very low and there is a general deficiency of organic matter. The extensive *salt* lands is a characteristic feature throughout Sind.

While frequent failure of the crop due to insufficient water supplies, is a feature particularly of the Karachi district. in other areas drainage has become a more serious problem than irrigation with a consequent fall in yields. The rice area in Upper and Lower Sind is transplanted except on the eastern side where it is broadcast. In the barrage area the season begins early and better varieties represented by the *Sugdasi* group are common and *rabi* crops are also grown after rice. Under the inundation canals owing to late receipt of water and the short period for which water is available, cultivation starts late and quick ripening varieties inferior in quality, with red kernel are more common.

Selection

Upper Sind. As part of the Bombay Province, the rice work in Sind was being attended to by the Deputy Director, Bombay Department of Agriculture, on farms situated in Larkana and Sukkur. In early years, experiments on cultural and manurial practices took a greater part of the time of the staff. Selection work was first started by the Cotton Botanist, Mr. Thadani and the varieties to receive his attention first were *Jajai, Sugdasi* and *Prong,* fine scented varieties, an early variety of *Sathi* and the popular high yielding but coarse *Kangni.* In 1923 the Sukkur farm was abolished as being unsuitable for rice work. With the appointment of Mr. Thadani as Economic Botanist at Sakrand the rice work at Larkana was transferred to his charge and by 1927 three strains *Kangni* 27, *Jajai* 77 and *Prong* 36 (*vide* Appendix III) were evolved for distribution to cultivators in Upper Sind. Intervarietal trials were also conducted and it was found that a pure line from an acclimatised fine variety called *Bengalo,* evidently introduced from Bengal, was useful. A strain in each of the scented varieties of *Sonahari* and *Sadagulab* was evolved which are yielding higher than *Jajai* 77.

Lower Sind. The varieties in Lower Sind as mentioned before, are all of short duration and of very inferior quality. As such the work on these varieties could not conveniently be undertaken at Larkana; a substation was, therefore, opened in Hyderabad district to deal with those varieties, the chief of which are *Motya, Ratrya* and *Gunja.* Selection work was started in 1932 and by 1937 three selections in *Motya,* two in *Ratrya* and one in *Gunja* were marked out as the most promising.

Dokri Station

With the opening of a station at Dokri in 1936 on the right bank of the Indus, to study the irrigation conditions of the post-barrage system in rice fields, the main work on rice was transferred to this station, the farm at Larkana serving only as a substation. The chief aim of the station was connected with agronomic aspects of rice cultivation including the study of the possibilities of conversion of non-established rice lands into dry crop areas and the evolution of a system of farming which would minimise the danger of water logging as a result of rise in the level of subsoil water consequent on inundation from rice fields.

Hybridisation. Crosses were effected at Larkana between the high yielding strain of the popular but coarse variety *Kangni* 27 with the strain *Kolamba* 184 of Bombay, which though fine grained, is a poor yielder under Sind conditions. One strain christened as *Silver Jubilee* was fixed for multiplication which in addition to being superior to *Kangni* in yield has a fine rice. One of the varieties called *Torh* is somewhat salt-resistant but a poor yielder, and in 1932 it was crossed with the heavy yielding *Kangni* 27 to combine the salt resistance of *Torh* with the good performance of *Kangni.* The progenies did not show much improvement over *Torh,* but one segregate somewhat better in quality, was selected and is being distributed to the cultivators. A few crosses were made between suitable parents for evolving high yielding early scented rices for Lower Sind and the work is still in progress.

What remains to be done

(1) Strains have yet to be evolved for Lower Sind from varieties common in that tract.

(2) The improvement of yields of fine-scented varieties *Sugdasi* and *Prong* largely grown in Upper Sind by suitable hybridisation.

PUNJAB

With about a million acres under rice, the Punjab is relatively of minor importance amongst the rice growing provinces of India. The province, however, produces rices of good quality like the *Peshawari, Dehradun* and *Amritsari* which are in great demand in the North Indian markets and which often fetch double the price of ordinary rices. In the Punjab there are two definite zones where rice is grown ; in one zone the crop is irrigated by the inundation canals and in the other the crop is grown on terraced hill slopes depending mainly on rains and small rivulets passing through them. Owing to the short season and the necessity to follow rice with a *rabi* crop, only short duration rices can be grown in the plains. About a quarter of the total rice area is transplanted, particularly under the Upper Chenab canal, and the rest is broadcast either in wet or dry condition of the soil. Where sown broadcast, the field is lightly ploughed when the crop is one month old with sufficient water in the field. On the plains the soil is clay loam, locally termed *saibat* and is typical of the Gangetic alluvium, extremely deficient in humus. In the *Kalar* tract, which is comparatively more important, the soil known as *kalrathe* contains a large amount of salt, and is very hard when dry and impervious to water when wet.

Of the several varieties under cultivation the early and coarse ones like *Jhona, Sathri* and *Toga* are the more important, as they give good outturns and can be followed by a *rabi crop*. The scented *Mushkan* group of rices is grown over particular areas only by big landlords. Special mention must be made of the '*Basmati*' group for which there is a great demand from many places in North India. The special points that are looked for in the polished grain of this rice are (1) a '*greasy*' look without any abdominal white, (2) an entire rice grain, (3) fully developed and uniform kernel and (4) neither too hard nor too soft when crushed under the teeth. The characteristics of cooked rice which are valued are (1) maximum elongation nearly double that of the uncooked grain, (2) individuality of cooked grains without bursting and (3) sweetness and a special fragrance of the cooked product. These rices, however, do not show any chemical composition different from other rices and several of the characteristics of the cooked rice mentioned above depend mostly on the way the rice is cooked.

Selection. Being of minor importance to the province, the rice crop did not receive much attention in earlier years. In 1926 however a rice station was opened in Kalashahkaku in the area commanded by Chenab canal and is under the immediate charge of Mr. Khan, the Assistant Cerealist, who has had special training in rice breeding in Madras. The station represents the *Kalratha* area, the major rice producing tract of the province. Samples of varieties were collected and pure lines numbering nearly 500 were isolated from these varieties and are maintained. From extensive comparative trials of varieties amongst the classified groups conducted on the station until 1938 it was possible to fix seven strains as the most useful for the cultivators (*vide* Appendix III).

It was realised that the Zamindars would prefer to have improved types in the varieties which they were themselves growing and single plant selection work was later started in the varieties of *Jhona, Mushkan* and *Begmi.*

Hybridisation. The following crosses are under study.

Basmati 370 × *Palman* 46 intended to combine earliness of *Palman* with the good quality of *Basmati.* The cross pursued up to F_5 generation showed it was not possible to combine earliness with quality.

Mushkan 7 × *Begmi* 41 intended to combine the good tillering of *Mushkan* with the earliness of *Begmi.* The work is still in progress.

Mushkan 7 × *Mushkan* 41 intended to evolve a non-shedding type with the heavy yield and fine grain of *Mushkan* 41. Some hybrids with the required combinations have been isolated. It is reported that one hybrid is particularly promising as it appears to be better in quality than *Basmati* 370 now under distribution.

New crosses recently made and which await study are (1) *Jhona* × *Honduras* (early) to evolve an early maturing *Jhona* type and (2) *Son* 16 × *Son* 14. to combine the white rice of *Son* 14 with the heavy yield of *Son* 16.

Recently the Indian Council of Agricultural Research have sanctioned a small investigation at this station, namely, study of the influence of weather, soil, etc. on the flavour and quality of *Basmati* rice. The problem is an important one as very little is known about the influence of environmental factors on quality. This investigation might throw light on the particular quality associated with this rice which is however different from quality from the nutritional point of view.

Hill rices. To study the rices grown on the hill slopes under a heavy rainfall with gravelly soil, a substation was opened in 1929 near Nagrota in the Kangra valley. A large number of single plant selections has been made in the more important varieties and the work is in progress.

Karnal Farm

With the opening of a substation at Karnal in 1931, by the Indian Agricultural Research Institute for the study of wheats, work on rice was also started on a portion of the station. This area gets the benefit of a higher rainfall than at Kalashahkaku and rice is grown with irrigation and is confined to the stiff low lying '*naili*' lands followed by a *rabi* cereal (wheat) or gram. Non-shattering, early maturing and high yielding varieties of the thin long grain type are liked in this area. Work was directed towards this and two types T.125 and T.130 with long slender grains were found to be the best in that group of rices. Another coarse red-kernelled pure line T.164 was also found to be a heavy yielder.

TRAVANCORE

Of the Indian States, Travancore occupies the first rank in the production of rice with an average output of 0.6 million tons from seven lakhs of acres. Though the area is negligible compared to the major rice growing provinces, the crop is very important, the area being a deficit one. Though the rice area is small, it includes a variety of cultural and soil conditions, *viz.,* (1) South Travancore with a rainfall of 40 inches and dependent upon artificial irrigation and frequently subject to severe droughts in the extreme south. Lower down in this area, nearly ten thousand acres are saline; (2) North Travancore (*Kuttand*), which consist of low lands subject to floods with long periods of submergence and (3) the '*virippu*' fields of Central Travancore confined to the narrow irregular terraces in the valleys and the lower slopes with an average rainfall of over 100 inches. It is subject to period of alternate submergence and drought.

The State opened a Rice Research Station at Nagercoil in 1918 in South Travancore which is under the control of the Economic Botanist. He made collections of several varieties of the tract and evolved some strains of rice. (*vide* Appendix III). But as already pointed out the rice area of the State has diverse conditions and one rice station was found inadequate to meet all the requirements. Hence two more stations were opened in 1940, one at Moncompu in *Kuttand* and another at Adoor in Central Travancore with the financial assistance provided by the Indian Council of Agricultural Research. The *Kuttand* area is a vast sheet of water from June to November and cultivation starts only from November. Ring bunds separating the fields from the rivers and lakes are raised, repaired and strengthened and water from within is pumped out by oil or gas engines. Sprouted seeds are sown broadcast as the fields get ready. Water in the rivers and the Vembanad lake becomes saline by end of February. So only very short duration varieties are grown here. The system of cultivation here is the same as the *cole* cultivation adopted in parts of South Malabar described in the *Hand Book on Rice in Madras* [Ramiah, 1937, b].

In certain high level areas in this tract a crop from June to October is again raised. Water in this area may be five to six feet at some part of the season. In some areas a single crop of a long duration deep water rice is attempted. Thus in a small compass we have diverse methods of cultivation. The immediate requirements are :

(1) For *North Travancore*, (a) the evolution of short duration high yielding rices ; (b) the evolution of high yielding flood resistant rices and (c) the evolution of saline resistant, short duration rices.

(2) For *Central Travancore* the evolution of heavy yielding and drought resistant strains of short duration.

(3) For *South Travancore* the evolution of heavy yielding, drought resistant types. These must also be flood resistant as such a contingency usually arises. The requirements of South Travancore have been met, in part, by the isolation of strains at the Nagercoil station (*vide* Appendix III).

Work with the above objects is proceeding in the two new stations. It began with a survey and collection of the several varieties, isolation of pure lines and also single plant selection from the more common varieties. For *Kuttand*, 450 selections were made in the most popular variety known as *Kalladа Samba*. The time during which the stations have been working is too short to report results but from the account it would appear material of promise has been accumulated.

Varieties and strains have also been introduced from other parts of India (Bombay, Madras and Mysore) and are being compared against the local varieties which are coarse with red kernel and it may be stated that only such types are in favour in this area.

HYDERABAD (DECCAN)

Rice is an important food crop of the Hyderabad State which has a little over a million acres with a production of 0.4 million tons. The area devoted to rice lies to the south and east of the State called the *Telingana* where the soils are granitic in origin and calcareous. The area under rice in the State is reported to be increasing owing to the development of irrigation projects.

Much of the rice area depends upon rainfall and small streams and tanks fed by rains. About 1,50,000 acres have an assured water supply fed by the Nizamsagar reservoir. Most of the rices grown in the rainfed area are coarse. The main agricultural station is situated at Himayatsagar commanded by Nizamsagar canal and work on rice has been going on here since 1928. Work on rainfed rices which cover about 1,00,000 acres has not yet been taken up.

Hundreds of varieties are grown in the rice belt which differ in duration, water requirements, grain quality, etc. There are two distinct groups, the short duration ones which are grown twice in the same year both in the *abi* as a monsoon crop and in the *tabi* as a summer crop and the long duration ones which are grown in the *abi* season only.

The rice improvement work was first started by the State Economic Botanist, Mr. Bhide and was continued later by Khurshid, his successor. Hundreds of samples of the popular varieties were collected and studied and from the promising samples selections were made. After preliminary tests and later large scale trials of these in the Governmental farms for two seasons, certain strains were recommended to the cultivators. Eight improved strains H.S. 1, 35 and 38 in the long duration group and H.S. 8, 12, 21, 22 and 27 amongst the short duration rices were isolated and released for general distribution among the rice growers of the State.

MYSORE

There is an area of 800 thousand acres under rice in Mysore State and the production is only 0.21 million tons. The agriculture of the Mysore State was always under the care of a well equipped and efficient department and systematic work on the improvement of crops was pursued as in the neighbouring province of Madras. The chief problems of the rice tract are : (1) improvement of the purely rainfed broadcast, coarse rices of the hilly *Malnad* tract where soils are generally poor with a fairly good rainfall ; (2) Improvement of the monsoon rices in the flat rainfed country in general and in the channel fed areas in particular ; and (3) Work on the summer rices grown in the low level lands which get some artificial supply of water from tanks during January to April.

In the early years of the Department. improvement of rice yields was sought by mass selection in the local varieties and introduction of established strains from the Madras Province. For the *Malnad area*, two coarse varieties known as *Honasu* and *Togarinu* were improved by mass selection and for canalfed areas, strains Geb. 24, Co. 1 and *Banku* from Coimbatore were successful. Geb. 24 known locally as *Coimbatore Sanna* soon became very popular and it is stated that in 1930 it occupied nearly 2,00,000 acres

In 1931, the rice work was reorganised under the control of late Dr. V. K. Badami, the Economic Botanist and the main work was later shifted to the Nagenahalli farm, representing the area fed by the Cauvery channels. Work for the *Malnad* area was taken to the Maruthur farm and that for summer rices to the Hebbal farm.

1. Nagenahalli Farm

The station was placed under the immediate charge of an Assistant Economic Botanist in 1929 and the main work of the station was evolution of strains suitable for the channel areas, though manurial and cultural experiments also receive attention. A large collection has been obtained from different rice stations of Madras and Bombay. The important local varieties were also subjected to progeny row selection ; later hybridisation was also started using Geb. 24 as one of the parents. From 1937 the Government have appointed a whole time Rice Research Officer, Mr. Sharma, who controls the work in all the rice stations. The strain Geb. 24 which had been introduced some years back and which had remained the most popular variety had deteriorated and selection work was undertaken in this by the Special Officer and it is reported some useful strains have been isolated by him. Since from Coimbatore experience it is known that there is usually a larger precentage of natural crossing in Geb. 24 than in other varieties, it is believed that the deterioration must have been the result of such crossing. The other strains evolved by the Paddy Specialist are described in Appendix III.

Crosses between Geb. 24 and a local variety *Gunasalae*, with the object of producing a variety with high yield, good hulling percentage and non-shattering character are reported to have been successful. Two strains X.18 and X.194 which are better than Geb. 24 by ten per cent have been obtained.

Two hundred and fifty pure lines are being maintained on the farm. A large number of selections numbering about 2,300 have been made in the more important local varieties for studies.

2. Maruthur Farm

The work at the Maruthur farm has for its object the improvement of *Malnad* rices. The system of rice culture varies in the tract. In most of the lands broadcasting is the rule and some of the fields are water-logged and heavily inundated. Broadcasting is done in May and transplanting where it is practised is done in July or August. Varieties have to be evolved to suit this diversity of conditions. Again Geb. 24 which was first tried on the station and was spreading because of its good yield was later reported not quite so wholesome as the local coarse *Malnad* rice which forms the exclusive diet of the people. Later work had, therefore, to be concentrated in the local varieties to evolve strains with high yields of both grain and straw as the latter is also important in the tract due to general scarcity of fodder. Selection was undertaken first in the three most popular coarse varieties, *Honasu*, *Walya* and *Togarina*. Two promising strains in each of *Honasu* and *Walya* await further testing on cultivators' fields. In 1941 the Maruthur farm was abolished and a new station has beer started at Bikli which is considered more representative of the *Malnad* tract. Crosses have also been made between the coarse red rice strains of *Malnad* with the heavy yielding white rice strains of Nagenahalli farm and are under study for evolution of better quality rices.

3. Hebbal Farm

For the *kar* season, January to April under tank irrigation, three successful strains have been produced and are stated to be popular with the cultivators.

BARODA

Rice occupies rather a minor position in the agriculture of the Baroda State. Its cultivation is carried on under two different conditions; (1) The open system, occupying 1,00,000 acres, includes coarse and drought resistant varieties of poor quality which are grown in alternate lines with cotton during the monsoon. The crop is entirely dependent upon rainfall. A bare or summer fallow with a *rabi juar* alternates with the cotton rice mixture. This system is about similar to that obtaining in parts of Madras Presidency. (2) The *kyari* or wet method carried on over 1,50,000 acres consisting of either drilling or transplanting as suited to the types of land and available irrigation facilities, namely, water stored in tanks during the monsoon. Obviously these two sets of conditions require different types of rice. The monsoon being of a short duration, varieties grown are, as a rule, early.

Early work on rice in the State was confined to trials of strains from Karjat (Bombay) with indifferent results. With the sanction of a rice research scheme by the Indian Council of Agricultural Research, systematic work was taken up in the year 1940. A number of strains was obtained from other provinces of India and tried under the above two conditions of cultivation. A large number of bulk samples of different 'open-cultivated' rice varieties were collected and a good number of single plant selections has been made in each of them. From observations so far made on the improved varieties under trial in the 'open-cultivated' conditions, it would appear that the local varieties are more suitable than the introduced ones. The work is still in the initial stages and it is too early to report on the results.

KASHMIR

Compared with the major rice producing tracts of India, Kashmir occupies a very unimportant position with only 3,00,000 acres under rice. The cultivation of rice here is, however, very peculiar and not to be found in any other place. Rice is grown even at elevations of five to seven thousand feet, the major portion of the area being situated at an elevation of four thousand feet. Rice forms the staple food of the people and occupies one-third of the cultivated area. The rices grown in the different altitudes must of necessity be different and hence there is a considerable number of varieties. Most of the area is broadcast beginning by about the end of April and extending to the end of May depending upon monsoon rains. Rice is here rotated with maize, barley and *urid* (*Phaseols mungo*).

Work on rices of the lower valley is being done at the Pratap Model farm from 1923 and following the methods of mass selection four improved varieties in *Baber, Lonanzen, Budiji* and *Mushka Budiji* were isolated by 1928 and these were found to yield up to 19 per cent more than the local bulks from which they were taken. Pure lines from other varieties were also isolated. An exotic Japanese type, *Piedmontese bertone* is said to be very promising.

The study of rice in Kashmir has more than local interest and so far as coordinated rice work in India is concerned it may be considered useful in the following ways :

(1) It can give information as to the behaviour of certain standard Indian rices under temperate conditions obtaining in Kashmir and thereby indicating to some extent, the climatic limitations of rices developed in other centres.

(2) Since some exotic rices do well in Kashmir, the area might be useful for making the first crosses with Indian rices.

Hence a scheme for rice research was sanctioned by the Indian Council of Agricultural Research which is being carried on at two substations one at 5,300 feet elevation and the other at 2,000 feet elevation.

Since the scheme started working only in 1940, it is too early to report on the results obtained. It may however be noted that some of introduced foreign rices, particularly, those from China are showing great promise. They are early and heavy yielding and better than local varieties in everyway.

BURMA

In Burma, which formed part of India until 1937, rice is grown over 11.2 milion acres with an annual output of 4.6 million tons. The great bulk of the population of the country is either directly employed in the cultivation, milling, transport, and shipping of rice or engaged in occupations which derive their prosperity from the rice industry. About three million tons of rice used to be annually exported from Burma and therefore the state of rice trade furnishes a fairly reliable barometer of the prosperity of the country. The activities of the Burma Agricultural Department are always linked up with the interests of rice traders and rice millowners in Burma.

Considerable amount of valuable work in breeding new varieties had been done in earlier years by the Economic Botanist in Mandalay, North Burma, and by the Deputy Director of Agriculture in lower Burma. In 1932, with the finance provided by the Indian Council of Agricultural Research, a post of Rice Research Officer was created and Mr. Grant was appointed to it with headquarters at Hwmabi.

Work after 1932

At the time rice research under the auspices of the Indian Council of Agricultural Research was initiated, Burma was losing her markets in the West and one of the objects of the scheme was to produce types suitable to the Western markets and thus regain the trade she had lost. A great deal of attention was, therefore, paid to this question in the programme of work at Hwmabi. The Western markets require a pearly, translucent, bold type of grain that will polish well and also 'glaze' well with the least amount of breakage in milling. Many of the Burma rices are soft with a certain amount of 'abdominal white' in the grain. It has been found that it is the bold shape of grain and hardness of the kernel that determine the amount of breakage in the extra polish and glaze that are given to suit the Western markets. The American rices, *Blue rose* and *Carolina* are preferred in the European markets because of these two qualities. Besides the European markets, the needs of Eastern markets in Java and the Philippines for small and round types similar to the Japanese rices had also to be met.

The rice improvement work on hybrid progenies which had been going on for several years even before the scheme financed by the Indian Council of Agricultural Research was launched, was considerably intensified later. Crosses between the best local kinds and the best exotic types from Japan and America were made and extensively studied to evolve types with as good a quality as the foreign types, combined with the yields of Burma rices. The work at Hwmabi station was conducted in close collaboration with the leading rice firms in Rangoon to gauge the suitability of evolved types for foreign markets. Most of the crosses with the exotics showed a good deal of sterility in their progenies though repeated selection had progressively reduced it in the later generations. The yields of the exotic hybrids were also not as good as the local parents. Backcrosses of the hybrid progenies with the Burma parents were later made and the resulting families were somewhat better than the original crosses but were not altogether desirable from many points of view. The studies have shown that it may be easy to produce types similar to the exotic types, Japanese and American, but it is extremely difficult to evolve a culture of normal field behaviour under Burma conditions, as the exotics are by nature sub-tropical requiring certain climatic and environmental factors entirely different from those existing in Burma.

But from amongst the crosses between the local varieties, some promising hybrids have been isolated in the F generation and were tried under field scale trials for two years at eleven centres in the districts. The results have confirmed the superiority of two hybrids xa. 97 and xa. 108, over the locals under Lower Burma conditions with good hulling outturns; the rice is bold, large, white and fairly translucent with little or no abdominal white. The Burma Chamber of Commerce considered them commercially good and suitable for both the Western and Eastern markets.

CHAPTER XI

ORGANISATION OF SEED SUPPLY

WHEN the breeder has decided upon the particular strain or strains as being the most suitable for a given tract, arrangements will have to be made to multiply them as rapidly as possibly and make the seed available to cultivators in that area. The crop grown on the experimental stations can meet only an extremely small fraction of the requirements. Again, owing to the special features of Indian agriculture, some of which are the small and scattered holdings, the special tenancy systems, the financial instability of the grower, etc., it is not possible for every individual cultivator to multiply his own seed from the improved types. It is necessary that there should be an organisation for the systematic multiplication and distribution of the improved seed amongst the cultivators. In the more advanced countries this work is done by private seedsmen. In India there are no seedsmen who deal in extensively grown agricultural crops. The work has therefore to be undertaken by the State. It may also be stated that many of the western countries have their Seed Acts by which only certified and pure seed can be grown by cultivators.

The extent of seed organisations varies in different provinces and States and according to the nature of the crop. Among the provinces of India, the Punjab is the only province, that spends a large amount annually on seed distribution schemes of various crops; in the case of wheat, this province spends annually twelve to sixteen lakhs of rupees for seed distribution work, which has been responsible for the spread of the improved type *Punjab 8-A* over nearly fifty per cent of the wheat area. Among States, Baroda has a very good organisation for seed multiplication Seed organisation may be divided into (1) maintenance of nucleus stock and multiplication of the same at the experimental stations and (2) large scale multiplication of seed and its distribution to the cultivators.

Maintenance of pure seed

It is not unusual to hear sometimes complaints from the cultivators that the original excellence of an improved strain deteriorates with lapse of time. Field scale trials were conducted in Burma [Grant, 1937], and Bengal [Hedayatullah, 1941] with seeds of improved strains from several sources, and it was found that there was no such deterioration even after the lapse of some years since the seed schemes were in operation. The so-called deterioration in types which are ordinary selections from natural populations has been always found to be due to the variety having got admixed with other varieties. Since it is not unusual for several varieties to be grown even in small areas by different cultivators, such mixing is extremely common. In the deltas where the harvested field is itself the temporary threshing floor, and when several varieties have to be threshed on the same floor such mixing is inevitable. Under such circumstances the original improved strain might entirely lose its identity after some years.

A nucleus seed stock of the improved strains released from any particular experimental station must be maintained at the station to serve as the primary source for seed multiplication. The best way to do this is to grow each strain of rice in a separate field, planting it in lines with single seedlings. The field will have to be gone over thoroughly at various stages of growth and all doubtful plants removed before they can contaminate the rest by natural crossing. At harvest the individual plants are gone over again and those in the centre of the plot alone saved for seed purposes. It is this seed that should be used for the primary stage. It is a sound policy to select from the improved strain at periodical intervals, say, once in three-four years, about 100 to 200 plants, grow them in progeny rows and, if possible, under replication. Those progenies which are representative and are high yielding and do not show variability can be bulked up, and this made to form the nucleus for further multiplication. In some of the experimental stations the practice obtains of selfing a few plants to provide seed for the primary stage of seed multiplication. This should not be necessary in the case of rice.

Largescale multiplication of seed and its distribution.

Considering the extensiveness of the rice crop in many parts of India and the fact that seed requirements alone of the country amount to about 2 million tons every year, the production of pure seed on a really large scale is a difficult problem. The area could be covered with improved types only gradually and for the work to go on efficiently, needs a sound organisation. The latest report of Agriculture and Livestock in India [1939-40] shows that only six per cent of the total rice area is covered by improved strains although this percentage is somewhat higher in some provinces than in others. This is not a satisfactory position since improved strains suitable for particular areas and conditions have been available even several years ago. The main reason for such a slow rate of progress is the absence of a proper and large scale organisation for multiplication and distribution of seed. Moreover, there is no means of correctly estimating the area under improved varieties. The figure mentioned represents only the area where seed taken directly either from Government experimental station or from private seed farms controlled by Agricultural Departments has been sown, and does not include the area covered by natural spread from cultivator to cultivator. For instance, in Madras where rice breeding has gone on for a much longer time than in any other province, the area under improved types is definitely very much higher than the official figures. In the deltas where there is great concentration of rice cultivation it is not unusual to find large areas in several villages devoted to a single strain recommended by the Agricultural Department. The Paddy Specialist, Madras, reports in a personal communication that the official figure given as the area under improved varieties in the province is far below the actual. He believes that actual areas under improved strains can be estimated only by a special rapid survey method.

Even in the case of cotton, where the area under improved strains can be correctly determined, and where an efficient organisation financed by the Indian Central Cotton Committee exists, the percentage of area under improved varieties is only 22 per cent. Things have, however, changed very much since this manuscript was originally written. Due to the great shortage of food in the country, the Central and the Provincial Governments are spending considerable sums of money on "Grow More Food" campaign. The multiplication and distribution of improved strains of rice forms an important item of work in this campaign as it forms a sure method of increasing production. This has resulted in the area under improved strains going up rapidly in recent years. In Madras for instance, it is stated that 50 per cent of the rice area in the deltas is now covered by improved strains.

(a) *Non-official agencies.* As has been stated already there are no seedsmen in India as in foreign countries. The small cultivator does try to maintain his seed requirements from his previous year's crop. It is only in times of famine or scarcity that he is obliged to go to the village trader who supplies seed of a non-descript type and charges heavy interest on the *sawai* system, sometimes as high as fifty per cent. Unless seed acts and laws are promulgated as in western countries, there is not much scope for private seedsmen to undertake the work for crops like rice. In villages, the small rice farmers whenever necessary get their seed requirements from the larger land owners. In fact the big zamindars who let out their areas in small units to tenants do supply seed to the tenants and take it back from the tenant at the time of harvest. Any seed scheme, if it is to succeed, must provide for the small grower to get his requirements at his doors without much difficulty.

(b) *Cooperative societies.* Cooperative societies could be utilised for production and sale of seed to the cultivators. Unfortunately, however, the contribution by the societies to this line of activity is extremely small. There are only a few societies in Bengal, Central Provinces and Madras who are doing this work. In no other Province or State have the Cooperative societies undertaken seed distribution work. As far as can be ascertained the total number of cooperative organisations in India engaged in the distribution of rice seed is probably less than fifty and the total quantity of seed handled by them is not more than 220 tons. It may, therefore, be taken that the role played by cooperative agencies in this important developmental work is quite negligible.

(c) *Government departments.* By far the largest distributing agency of improved rice seed to the cultivators is the department of agriculture either directly from the produce obtained at their experimental stations or indirectly through seed farms, Union Board farms, demonstration centres, Court of Wards' estates, private seedsmen, registered growers, growers' associations, etc. Generally speaking the pedigree seed of improved strains is not issued directly to the growers for general sowing. It is in most cases multiplied through the agencies mentioned above which work under the supervision of the agricultural department. The methods adopted in different places to distribute seed multiplied in seed farms are essentially the same but differ only in detail.

It may be pointed out here that money spent on seed multiplication programmes, is not a gross expenditure to Government but only represents a sum invested and later recouped by the sale of seed. Owing to fluctuations in the market rates and charges under organisation, it is possible that a small loss may be incurred but considering the practical benefits accruing from the programmes this loss can be ignored. It is stated that the wheat distribution scheme in the Punjab is self supporting.

In Bengal there is a Government farm practically in every district where strains evolved at the breeding stations are first tested. When particular types are found suitable they are either multiplied or supplied to Court of Wards' estates, agricultural associations and Government subsidised Union Board Farms, where this seed is multiplied and then distributed to cultivators. It is stated that in 1939 there were 572 such farms. The actual distribution of the seed, however, is not done under Government supervision. Thus it is not possible to gauge how much area was covered by them and there is also no efficient control to prevent admixtures. In 1942, however, the Government had sanctioned a scheme costing 16 lakhs of rupees for supplying enough seed to plant 5,00,000 acres in 1943 season. There are also approved growers to whom departmental seed is supplied and grown by them under departmental supervision and the seed purchased from them by Government and distributed to cultivators on *sawai* system, 1¼ maunds to be recovered for one maund of seed advanced.

In Madras, the seed farm is the most widely operated unit. The Deputy Director of a circle selects a number of reliable and enthusiastic cultivators and an agreement is entered into with them, by which they agree to grow the variety recommended, rogue and thresh the crop as per instructions and under departmental supervision. Further the growers have to return an equal amount of the seed first advanced to them and also to sell a minimum portion of their produce to the Government at prices which are slightly higher than the market rate for ordinary rice. Sometimes advances are made to the growers for meeting additional expenses which are recovered along with the Government rent. The seed obtained from these seed farms is stored in agricultural depots and then distributed to the cultivators. The system though good has not made much headway for the reasons that (1) the Deputy Directors are not provided with sufficient funds for the purchase of seed in large quantities and (2) there are no adequate facilities for drying and storing large quantities of seed. As will be seen from their reports, only 1,000 tons of seed was produced and distributed in this way in 1939. In 1942, however, with the undertaking of 'Grow More Food' campaign financed by the Central Government it is reported that sufficient seed has been multiplied to cover half a million acres in one season. The provincial government has also made liberal grants amounting to several lakhs of rupees in the last year or two to organise special seed farms for multiplication and distribution of improved seed in selected districts.

In Bihar, where improved types of rice have been released for distribution only recently, small quantities of seed produced on the experimental stations are distributed directly to the cultivators. It is reported, however, that a scheme costing about a lakh of rupees for speeding up the distribution of certain improved types has been recently sanctioned and put into effect.

In the United Provinces certified seeds are distributed to selected private farmers who own blocks of land at convenient distances from Government seed depots. The seed is bought by Government and stored in Government godowns and then distributed to the cultivators in any one of the following ways :—(1) *Sawai* system under which the cultivator returns 25 per cent more in kind at the time of harvest and also undertakes to sell seed to Government if required to do so ; this is the most common method. (2) Seed is exchanged for an equal amount of ordinary grain available with the cultivator and the loss due to small differences in price between the two is debited to departmental charges. (3) By *takkavi* loans and five-year interest-free loans. In the first case the cultivator is granted a loan with which he purchases the seed, and in the second where larger quantities are involved the individual cultivator returns an equal quantity of seed after five years and also undertakes to sell a certain portion of his crop to the Agricultural Department, if wanted.

In the Central Provinces, seed is first multiplied on Government farms and directly distributed to the cultivators. But it is generally given to *Malguzars* who undertake to multiply and distribute it to their neighbours. The Department also supplies seed to seed unions organised in rural tracts with at least ten members for each union. Loans are advanced to unions for the purchase of seed. Thus apart from the initial supply of seed, the Agricultural Department does not exercise any control in maintaining the purity of seed.

In Orissa, until recently, there was no organised seed multiplication and distribution scheme except for a small quantity sold directly from its research stations. Since 1942, however, with grants provided by the Central Government for seed schemes, six seed-farms have been opened, in the districts. In addition to the above, a certain number of registered growers has also been selected. The seed farms and the areas of the registered growers are supervised directly by *Sirdars* appointed by the Agricultural Department. The seed farms get the first preference for seed from the research stations, and registered seed growers generally get their seed from the produce of seed farms. The registered seed growers are bound to sell fifty per cent of their produce to the Government which is stocked in convenient places from where it is sold to cultivators by the Department.

In Bombay, with the help of District Village Improvement Committees formed by the Agricultural and Revenue Departments, improved seed from the Government farms is grown in what are called registered areas in compact blocks in a few villages. The seed from these areas is distributed to other people on exchange basis by the Government.

Seed distribution in the Punjab has always received considerable attention of the Agricultural Department. Seed raised at the research stations and Government farms is first issued to large *grantee* estates on condition that the seed is multiplied under Government supervision and sold back to the Department. To enable the Department to buy large quantities of seed there is enough provision made in the Departmental budget. Sale of departmental seed is in the hands of non-official commission agents who furnish security, stock and sell Government seed, on a commission basis of two to three annas per maund of rice seed sold. An obvious drawback in this method appears to be that the agents are responsible only for the cash value of the stock they are entrusted with and there is no check on the method of disposal of the produce. The system has, however, this great advantage that the area under improved strains can be very rapidly increased. With a closer departmental supervision of the sales transacted by the agents there is no doubt that this is an ideal system.

In Sind, departmental rice seed first grown on two multiplication farms with an area of about two hundred acres each, is distributed first to more or less permanent registered rice seed growers, each of whom agrees to grow two hundred acres of the improved strain. The Government has the option of buying as much seed as is required from the produce of the registered growers. Most of the seed is sold by the Department from Government godowns where this seed is brought and stocked.

In Mysore State, seed distribution is sufficiently well organised. Seed from the experimental stations is given to agricultural and experimental Unions, Farmers' clubs and also intelligent agriculturists who should return the seed with ten per cent extra seed and also sell to Government as much seed as the Government wants. The seed which is purchased by the Government from these agencies is stored at various centres by the Department and sold to cultivators. Losses in purchase, etc., are debited to Government grants. Almost similar agencies are organised in Nizam's dominions and Baroda.

In Burma, rice seed distribution work forms one of the most important activities of the Agricultural Department. In fact this is the main line of activity of the agricultural staff in Lower Burma. When a strain is found to have passed the tests at the breeding stations, its seed is first grown on Government owned seed farms which are leased to tenants who pay rents in kind. There are certain conditions and concessions attached which include a rebate up to twenty per cent of the rent if the crop harvested is 99 per cent pure. The grain rent obtained from these farms is disposed of as seed by the District Agricultural Officers direct to local cultivators, whilst the non-rent portion in the hands of the tenant is disposed of by him under the instructions of the District Officer. There are two kinds of seed farms classed as major and minor; the major ones usually having storage accommodation provided by Government and situated at the headquarters of the local Agricultural Demonstrators, the minor ones having only storage accommodation provided by the tenant. The major seed farms receive requirements each year direct from the experimental stations and the minor seed farms take their supplies from the major seed farms. In 1937 there were 23 major seed farms with an area of 2,800 acres and 150 minor farms with an area of 9,500 acres. Besides the above, there is also a certain number of private cultivators who volunteer to take seed from either the major or minor seed farms, multiply it and distribute it to the cultivators maintaining at the same time records on special forms provided by the Department showing the quantity and destination of seed disposed of by them direct.

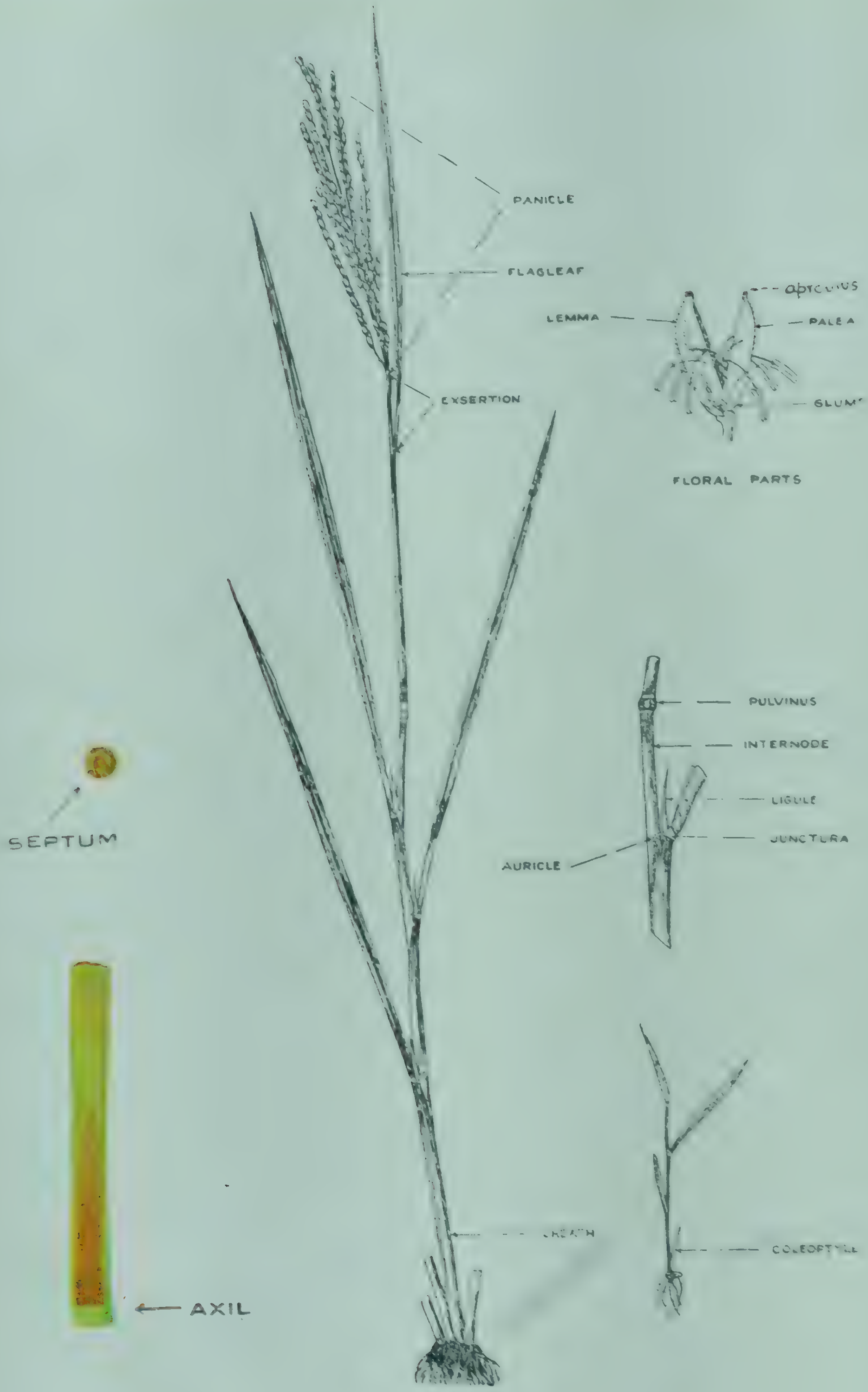
In Japan and Korea, the distribution of improved seed has been carried out systematically by establishing a network of seed propagation farms covering the whole country, and it is estimated that nearly 70 per cent of the area is covered by improved strains of known parentage, there being a good control over distribution of the seed by Government.

Registration of varieties

In Europe and America, in the case of more important crops, varieties and strains already in cultivation are registered as standard varieties. New varieties are not registered or named unless they are distinctively different from the existing varieties in one or more recognisable characters and are more prolific. This is a very sound system as it prevents the foisting of
more prolific. This is a very sound system as it prevents the foisting of
any new variety on the farmer by the seedsmen without ascertaining the

In India, where the several Provincial and State Departments are yearly producing a large number of new strains in crops, registration of strains, it has been considered, should be of value. As a beginning, registration of the wheat strains has been taken up by the Botany Division of the Indian Agricultural Research Institute at New Delhi. A similar procedure would probably be necessary for rice as well, where the number of strains issued by the Departments is even larger. The collecting, maintaining and describing this material will have to be done by the newly established Central Rice Research Institute at Cuttack. After some years it should be possible to register first all the improved types which are under distribution to the cultivators in the Provinces and States. This kind of registration is already in practice in Burma though their descriptions according to the standardised plan remain to be done. Special schedules for describing rice material are already available.

PLATE IX


PANICLE
FLAGLEAF
EXSERTION
LEMMA
apiculus
PALEA
GLUME
FLORAL PARTS
PULVINUS
INTERNODE
LIGULE
JUNCTURA
AURICLE
SEPTUM
SHEATH
COLEOPTYLE
AXIL

Parts of the rice plant

(After Huthinson and Ramiah, 1938)

PART III—GENETICS OF RICE

RICE plant offers an interesting material for genetical studies as the variations in the several morphological as well as physiological characters are enormous. The first record about the inheritance of characters in rice was made by Van der Stok [1908] from Java. The study has since been pursued in several countries and Matsura [1933] has made an admirable compilation of the genic analysis of results available up to the end of 1929. He lists 118 characters of which 76 are governed by single genes, 26 by two genes, 7 by three genes and the rest by multiple genes. The position has been revised later by Jones [1936], Hutchinson and Ramiah [1938] and Kadam and Ramiah [1943]. The contributions have come mostly from Japan, India and the United States of America. In the early years all the genetical work was confined to the study of morphological characters and it is only during the last decade that studies on the inheritance of physiological and quantitative characters have been undertaken. In the pages that follow an attempt has been made to bring together all the results of inheritance studies available in India up to 1945 including briefly a short account of studies made elsewhere.

To avoid confusion and to follow the nomenclature adopted in this publication a certain number of plates is given. Where definite proof was available that a character dealt with by two different authors was one and the same though described differently, definite genic symbols have been given. There is at present a great deal of confusion in the use of genic symbols for different characters and the whole position has been examined by Kadam and Ramiah [1943] who have drawn up a new scheme of symbolisation taking the one adopted for maize as a model. This scheme was circulated through the Commonwealth Bureau of Plant Breeding and Genetics, Cambridge, to most of the rice workers in India and abroad and the suggestions mainly from American workers have been incorporated. It has to be stated however that the scheme cannot be taken as final, as changes may be found necessary as our knowledge on the genetics of the plant increases. For example, where multiple factors have been suggested for any particular character, the actual identity of genes is not yet definitely established. This new scheme of symbolisation, further revised in the light of data furnished in this publication, is given in Appendix IV.

CHAPTER XII

ANTHOCYANIN PIGMENT IN RICE

THE presence or absence of anthocyanin colour in the different organs of the rice plant which can be easily seen and described, has received considerable amount of attention by many investigators. In fact, the early studies on rice genetics were confined mostly to this aspect. An intensive study made on the presence of anthocyanin in plant parts has shown that though unimportant by itself does occasionally show some genetic association with such important characters like spikelet sterility, vigour of the plant and even productivity [Ramiah 1935]. The intensity of pigmentation in the organs of the rice plant is influenced a great deal by the environment. Plants fully exposed to light on the borders of the field develop a deeper pigmentation than those in the middle. Very vigorously growing plants, for example, those in an unusually fertile patch, show comparatively less development of pigmentation than plants in an unfavourable environment such as lack of water, overcrowding, etc. The colour wherever present is most distinct just when the plants reach the reproductive stage. Except in the case of stigma, light is always necessary for the full development of colour in all parts.

Apart from the intensity of the pigmentation being influenced by environment, its presence or absence in a particular organ is a constant feature and has often been used for classifying varieties. The pigment, which occurs in the cell sap, has been generally referred to as purple in the publications. But its actual appearance to the naked eye may vary according to the intensity of the pigment and the depth of chlorophyll colour of the tissue in which it is present. Thus in the epidermis of dark green leaf sheath, the anthocyanin appears bluish, whereas in an otherwise colourless stigma it appears reddish in low concentrations and almost black when highly concentrated.

The examination of rice collections at different places shows that while there is a large number of types with pigment in different parts of the plant, there is a still larger number with absolutely no pigment in any part. There does not appear to be any selective advantage in the presence of pigment in the different organs. It has to be remembered that wild rices do not show any deep pigmentation in its parts and that among cultivated varieties those with deep pigment in several organs are rather rare.

It would appear that the production of pigment in any part of the plant is governed by two complementary genes corresponding evidently to the chromogene base and the oxidising enzyme, Parnell *et al.* [1917], Yamaguti [1932], Nakayama [1935] and Kosaka *et al.* [1938]. These two genes are designated A and C in the new nomenclature. The occurrence of ratios like 15 : 1, 27 : 37, 87 : 175, etc., for the presence and absence of pigment in particular organs shows that besides the basic genes there must be others responsible for localising the pigment in particular organs. Besides, there are also intensifying and diluting genes. Moreover, varieties which outwardly appear similar in colour characters may be found on closer examination to have the colour situated in different parts of the cell anatomy; for example, in the leaf sheath and in the internode, some varieties may have the colour situated in the parenchymatous cells only, other in the vascular bundles only and still others in both together. These different patterns are themselves governed by individual genes. The probable number of genes involved in the production of different types of pigmentation in the various organs are mentioned below :

Organ of plant	*Probable number of genes*
Leaf sheath	5
Internode	3—5
Junctura	2
Auricle	2
Ligule	3
Leaf axil	2
Pulvinus	2
Septum	2
Glume	2—3
Lemma and palea	4—5
Apiculus of above	4—5
Stigma	5—7
Leaf blade (lamina)	3
Awn	3

There is very little critical information available yet about the inter-relationship of these genes, and this study would require much more investigation with a large number of test crosses. From the published results, however, there appears to be a definite connection between colours in the different organs, the colour appearing in different combinations or patterns. The purple pigmentation occurring in two or more different organs behaves very often as if a single gene was involved. Takezaki [1921 and 1923] has observed that purple leaf (lamina) is always associated with purple colour in stigma, awn, apiculus, glume and leaf sheath. Yamaguti [1927] has recognised that the deep purple colour in the apiculus is always associated with purple colour in the glume, lemma-palea, internode, leaf sheath, leaf lamina, awn and stigma. Hector [1922] has also demonstrated that the purple apiculus is intimately connected with colour in (1) leaf sheath, (2) leaf sheath and stigma, (3) leaf sheath, stigma and internode, (4) glume, lemma-palea, leaf sheath, internode, junctura and auricle and (5) stigma and internode. Parnell *et al.* [loc. cit.] have shown that a purple colour in the internode and lemma-palea was closely associated and similarly colour in leaf axil and stigma. Chao [1928, a] has shown associations between colour in apiculus and stigma, between colour in leaf sheath and stigma and between colour in the leaf sheath and apiculus. Ramiah (unpublished records) referred to again in the chapter under linkage, finds that in one cross the presence of colour in a large number of parts gives a 3 : 1 ratio to its absence as if a single gene was only responsible. The above mentioned findings can result either by a single gene being responsible for production of pigmentation in a number of parts or the genes being different are closely linked. That in the varietal collections, types do occur with pigment only in a few parts is proof against the former possibility. That aberrant types, crossovers, do occasionally occur in hybrid progenies may be a proof that the different genes are linked.

It will probably be interesting to examine the distribution of pigment in the different organs as observed in the large number of varietal collections. Out of about 1,100 types maintained at the Paddy Breeding Station, Coimbatore, 446 show pigment in some organ or other. Altogether 13 organs, namely, leaf sheath, internode, junctura, auricle, ligule, pulvinus, septum, leaf axil, stigma, glume, lemma-palea, apiculus and leaf blade have been considered and the tabulation of the 446 pigmented types according to the presence or absence of colour in the above thirteen parts (not taking into consideration either the intensity or the nature of distribution of the pigmentation) gives 108 groups, there being present no group in which colour was absent in less than two organs. Occurrence of pigmentation in the thirteen organs if it was absolutely at random should give a very much larger number of groups than 108. While particular groups are found to occur in large numbers, certain others either do not occur or occur only very rarely. The most largely occurring group is that where colour is present in leaf sheath, pulvinus, septum, axil, stigma and apiculus. The next three largely occurring groups are (1) sheath, axil, stigma and apiculus, (2) sheath, internode, pulvinus, septum, axil, stigma and apiculus and (3) sheath, pulvinus, axil, stigma and apiculus. Examination of Table V showing the theoretical frequencies on random basis and the actual frequencies of the different pigmentation groups shows that there is considerable deviation between the two where groups with a large number of pigmented organs are considered but the deviation is not high where groups with less number of pigmented parts are considered. The data was utilised by calculating the X^2 to show the independence or otherwise of the presence of pigment in each of the thirteen parts with every one of the other twelve and this has given some interesting inferences mentioned below :

1. Colour in the leaf sheath does not show any association with colour in any other part.
2. Colour in the internode is not independent of colour in junctura, glume, lemma-palea and leaf blade.
3. Colour in the junctura is not independent of colour in auricle, ligule, glume, lemma-palea and leaf blade.
4. Colour in the auricle is not independent of colour in junctura, ligule, glume, lemma-palea and leaf blade.
5. Colour in the ligule is not independent of colour in junctura, auricle, glume, lemma-palea and leaf blade.
6. Colour in the pulvinus is not independent of colour in junctura and ligule.
7. Colour in the leaf axil is not independent of colour in stigma.
8. Colour in the stigma is not independent of colour in leaf axil.
9. Colour in the glume is not independent of colour in internode, junctura, auricle, ligule, lemma-palea and leaf blade.
10. Colour in the lemma-palea is not independent of colour in junctura, auricle, ligule, glume and leaf blade.
11. Colour in the leaf blade is not independent of colour in junctura, auricle, ligule, glume and lemma-palea.

The above would strongly indicate the presence of two definite independent groups, one in which pigmented junctura, auricle, ligule, glume, lemma-palea and leaf blade all go together, and the other in which pigmented leaf axil and stigma go together. The occurrence of coloured internode with coloured lemma-palea as in 2 and 9 and the association of colour in leaf axil and stigma as in 7 and 8 of above would appear to confirm the findings of Parnell [loc. cit.] already referred to.

TABLE V

Theoretical and actual frequencies of different pigment groups in Madras collections

Number of plant parts in which pigment is present	Probability	Theoretical frequency	Actual frequency	Deviation	X²
13	·0012	·0536	12	+11·9464	2062·62
12	·00159	·7096	12	+11·2904	179·64
11	·00928	4·1414	19	+14·8586	53·31
10	·03491	15·5795	35	+19·4205	24·21
9	·08728	38·9510	44	+5·0490	·65
8	·15710	70·1101	26	—44·1101	27·75
7	·20947	93·4816	61	—32·4816	11·28
6	·20947	93·4816	85	—8·4816	·77
5	·15710	70·1101	74	+3·8899	·22
4	·08728	38·9510	58	+19·0490	9·32
3	·03491	15·5795	14	—1·5797	·16
2	·00928	4·1414	6	+1·8586	·83
1	·00159	·7096	0	— ·7096	·71
0					
	·99938	446	446		2971·47

Similar classification of varieties according to the pigment groups has been done by Hector [loc. cit.] in Bengal varieties and by Jones [1929] with regard to varieties collected from Japan, Korea, China, Java and Philippine islands and grown in America. Hector had classified the 211 pigmented varieties according to presence of colour in 11 parts and obtained 51 groups. Of these the three groups most widely occurring were (1) coloured leaf sheath and apiculus, (2) coloured leaf sheath, internode and apiculus, and (3) coloured leaf sheath, apiculus and stigma. Jones's collection consisted of 311 pigmented varieties and he made out 48 groups according to the presence of pigment in 11 morphological parts. The parts considered by Hector and Jones have ten in common. According to Jones the most widely occurring groups in the order of their frequency are (1) pigmented glume, apiculus and awn, (2) pigmented apiculus and awn, (3) pigmented glume and apiculus, and (4) pigmented glume, apiculus, awn and stigma. It is seen that inspite of the fact that ten of the morphological parts considered were identical in the studies of Hector and Jones, the types of associations are different. The only common feature between the two is the association of pigmented apiculus and pigmented stigma.

Since the morphological parts studied for the presence of pigment at Coimbatore are not the same as those of Bengal and America, it is not possible to strictly compare all the three collections. While some additional parts over those dealt with by Hector and Jones have been considered at Coimbatore, awn was not one of these. The number of awned types is definitely less in Coimbatore collections and the occurrence of such a large number of awned types, 211 in Bengal and 311 in America appears to be a special feature of these collections. It might be there is a certain amount of preference shown to awned types in these regions. A joint tabulation has, however, been made of all the three collections, Coimbatore, Bengal and America, taking into consideration nine morphological parts only which were common to all and this gave 442 varieties of Madras divided into 58 groups, 211 varieties of Bengal in 34 groups and 281 varieties of America in 32 groups, i.e. the total collections of 934 varieties fall in 90 pigment groups [Ramiah, 1945]. This tabulation also showed that the occurrence and frequency of different pigment groups were different for the three regions. There is probably a slight similarity between the Coimbatore and Bengal collections as several of the groups are represented at both the places though with considerable differences in their frequencies. It may be seen that certain of the groups not represented either in Coimbatore or Bengal occur in America and *vice versa*. Test of independence or otherwise of the presence of pigment in each of the nine parts individually with the other eight by X^2 test, gave the following definite groups of associations :

Madras one group : showing pigment in auricle, ligule, glume and lemma-palea. In all probability internode also goes with the above.

Bengal three groups : (1) leaf sheath and internode, (2) auricle, pulvinus and stigma, (3) glume and lemma-palea.

America one group : leaf sheath, internode, auricle, ligule, pulvinus and stigma.

It is evident now that the presence of pigment in different morphological parts appears in different patterns or groups which are often met with in inheritance studies. When it is remembered that the material studied at the three places represents distinct varieties under cultivation in the respective regions, human selection showing preference to particular types must have gone on independently and there is obviously no preference shown to the same types in the three regions considered It may also be argued that with the enormous number of pigment groups that could possibly occur purely from theoretical considerations, even the collections examined at the three centres can but form only small samples. It is possible several pigment groups not represented in the present study might still exist.

It is not definite whether the colour in the rice pericarp comes under the same category of anthocyanin pigment. The purple pericarp colour probably does. Coimbatore work (unpublished records) does show that purple rice goes with the same anthocyanin group showing pigmentation in internode and lemma-palea. With regard to red pericarp colour there is definite evidence to show its association with one of the basic anthocyanin genes. Hector [loc. cit.] considers that the red pericarp colour is due either to the same gene causing purple pigment in the ligule or the two are different but closely linked. The presence of a few types with purple ligule and white rice, he thinks, supports the latter view. This does not, however, appear to follow from the examination of the varietal collections maintained at Coimbatore. Ignoring the large number of types where the rice is red even though there is no anthocyanin pigment in any part of the plant, among the types that do show pigment in some organ or other the association mentioned by Hector does not appear to hold good. A rough examination gives 54 types having purple ligule and red rice, 59 types with purple ligule and white rice and 144 types with white ligule and red rice. The second group of which Hector says only a few cases occur in Bengal, appears to occur with as equal frequency as the first in Coimbatore material.

While considering the association between the presence of pigment in different organs of the rice plant, it was mentioned earlier that the evidence so far available would rather indicate that the genes responsible for producing colour in different parts are different but remain linked. This, however, does not completely shut out the possibility that a single gene in a particular combination may produce colour in more than one part. Chao's work [loc. cit.] would appear to indicate that one of the complementary genes for apiculus colour is also responsible for production of colour in the stigma. Similarly there is an indication that one of the complementary genes for stigma colour may be the same as one of the complementary genes for production of colour in the leaf sheath. While he did not get any cross-over types, which he should have, if the genes are different but remain closely linked, it may be said that the population he studied was not large. If it could be established that the same gene produces pigment in different organs, it would involve postulation of a multiple allelomorphic series. A common feature of the multiple allelomorphic series is that its members control the expression of a character in different parts of the plant. This leads to the question whether such systems indicate independent control of several processes by a single gene (pleiotropy) or whether several very closely linked genes are concerned. The decision between multiple allelomorphism-cum-pleiotropy and close linkage is of some importance for genetical theory since the alternative entails radically different conceptions. A characteristic feature of experiments involving some multiple series is the regular appearance of occasional aberrant types different from the parents which could not be expected on the basis of multiple allelomorphism. In discussing allelomorphism with pleiotropy versus linkage, the occurrence of the aberrant types could not only be mutants on the basis of the former and cross-overs on the basis of the latter. In the case of linkage hypothesis there should occur the two complementary cross-over types in approximately equal numbers.

In the colour pattern associations recorded in rice there are frequent breakdowns with new types other than the parents produced in the crosses, and they have been explained as cross-overs. Parnell and others [loc. cit.] have actuallly shown that where linkage between presence of colour in internode and lemma-palea on one side and colour in leaf axil and stigma on the other, was established, the two complementary cross-over types arising from a breakage of linkage between colour in internode and colour in lemma-palea did occur in approximately equal numbers. There was no evidence of breakage of linkage between colour in leaf axil and colour in stigma and the only evidence of two genes being linked in this case is indirect, namely, the occurrence of types with colourless axil and coloured stigma and coloured axil and colourless stigma. In contrast to the above, Hector [loc. cit.] has explained four cases where the expected pigmentation patterns did break in his crosses. Although he explains them as due to breakage of linkage, the cross-overs are all of one type only and the complementary types are not recorded as having occurred. This result, if correct, does go against the linkage hypothesis. Ramiah (unpublished records) referred to in the chapter on linkage has observed definite breakage of pigment pattern systems in the crosses he studied and the results would appear to support more the theory of linkage and cross-over. The only snag about the linkage hypothesis is that the cross-overs occurred in extremely small proportions, of about the order of 0.02 per cent. In one case one of the aberrant type had to be explained as a double cross-over. Moreover, these aberrant types occurred not in the F_2s but in F_3s and later generations of the crosses. This difficulty can, however, be explained that when the percentage of cross-over is extremely small, it will not be possible to obtain them in F_2s unless a very large population is grown of them. The evidence so far available in rice would appear to support the theory of linkage but would need more definite evidence. Unfortunately such aberrant types obtained in earlier studies were not followed up nor tested genotypically, and close linkage has yet to be finally decided.

Rice appears to offer the best scope for making a critical test of the question of the alternative hypothesis of multiple allelomorphism. Suitably selected parents should be crossed, large F_2s grown and the aberrant types tested genotypically. Such a study would be valuable and throw light on the organisation of the gene. Further research would appear to be called for about the anthocyanin pigment itself particularly with regard to its course in the evolution of the cultivated types, and its role in the physiology of the plant.

CHAPTER XIII

INHERITANCE OF MORPHOLOGICAL CHARACTERS

1. ROOT

THE only case reported of inheritance studies of root characters is regarding its colour. Kadam [1938] found that a variety developed red colour in roots when exposed to sunlight. By crossing this variety with a normal white rooted variety he obtained a 9 : 7 ratio of colour to no colour in an F_2 population and this was confirmed in F_3 studies. Analysis of other gene effects in this cross (unpublished records) has shown that one of the genes **A**, is the major gene responsible for the production of anthocyanin pigment. The specific gene governing development of colour in root is designated **Rp** which acts only in the presence of **A**. In many crop plants colour of roots has been found to be governed by either complementary or duplicate genes.

2. STEM CHARACTERS

(A) *Ageotropism*

Normally the stem of rice, as in most of the grasses, is negatively 'geotropic' i.e. it grows upright from the surface of the soil. In examining the mutations from X-rayed material at Coimbatore, a plant with prostrate habit was isolated by Ramiah and Parthasarathy [1936]. Seedlings raised from the seed of this plant gave 28 prostrate and 12 erect plants, which led the authors to conclude that the prostrate or ageotropic habit was dominant. Later work has, however, proved that this interpretation was wrong.

In the next generation seventeen prostrate plants gave 1,329 prostrates and 83 normal plants. These few normal plants in a large population of prostrates would either represent a reverse mutation or natural crosses with normals. To clear the doubt a certain number of plants in each of the prostrate and erect groups was selfed and in the next generation the prostrates gave only prostrate progeny. The segregating erect plants gave range of ratios varying from 3 : 1 to 5 : 1 of normal to prostrate.

Another significant fact was that some of the prostrate plants were always throwing a few erect plants in their progeny which would suggest that the gene is unstable. Examples of such reversible mutations are common in plant kingdom. The data thus leaves very little doubt that the *lazy* or *ageotropic* mutation is a simple recessive and that the gene is highly mutable. The greater death rate of ageotropic plants had probably distorted the 3 : 1 ratio of normal to ageotropic plants in the earlier observation (Plate X).

Jones and Adair [1938, a] obtained a similar *lazy* or *ageotropic* mutation in a pure line of rice and in the F_2 of a cross between this mutant confirming the recessive nature of the mutation. The gene controlling the
confirming the recessive nature of the mutation. The gene controlling the
lazy habit is designated **la**.

(B) *Habit*

(1) *Spreading versus compact*

There is a great range of variation with regard to habit of the stem. By the term *habit* is here meant the manner of arrangement of tillers and the magnitude of their inclination to the vertical plane. At one extreme we have the wild rices with a typical procumbent habit. Among the cultivated types, though habit does never take this extreme form, there are varieties whose tillers arise at an angle from the ground which may be termed *spreading* varieties and others where the tillers rise absolutely vertical and remain so, until the end of the flowering phase, which may be called *compact* varieties (Plate XI).

In crosses among cultivated rices, Ramiah [1930] found compact habit a simple recessive, and the spreading forms were variable. This result has been confirmed by studies in the Central Provinces [Dave, 1939]. He also found that in a cross between a wild rice with procumbent habit and a cultivated rice with compact habit, the procumbent habit was a simple dominant to the compact habit, and the F_1 backcrossed to compact parent gave half and half of procumbent and compact plants in the next generation. The genes governing the procumbent and spreading habits may be designated **Er** and **Es** respectively.

The relationship between procumbent and spreading habit has not been studied so far. It is possible that the procumbent, spreading and compact habits form a multiple allelomorphic series.

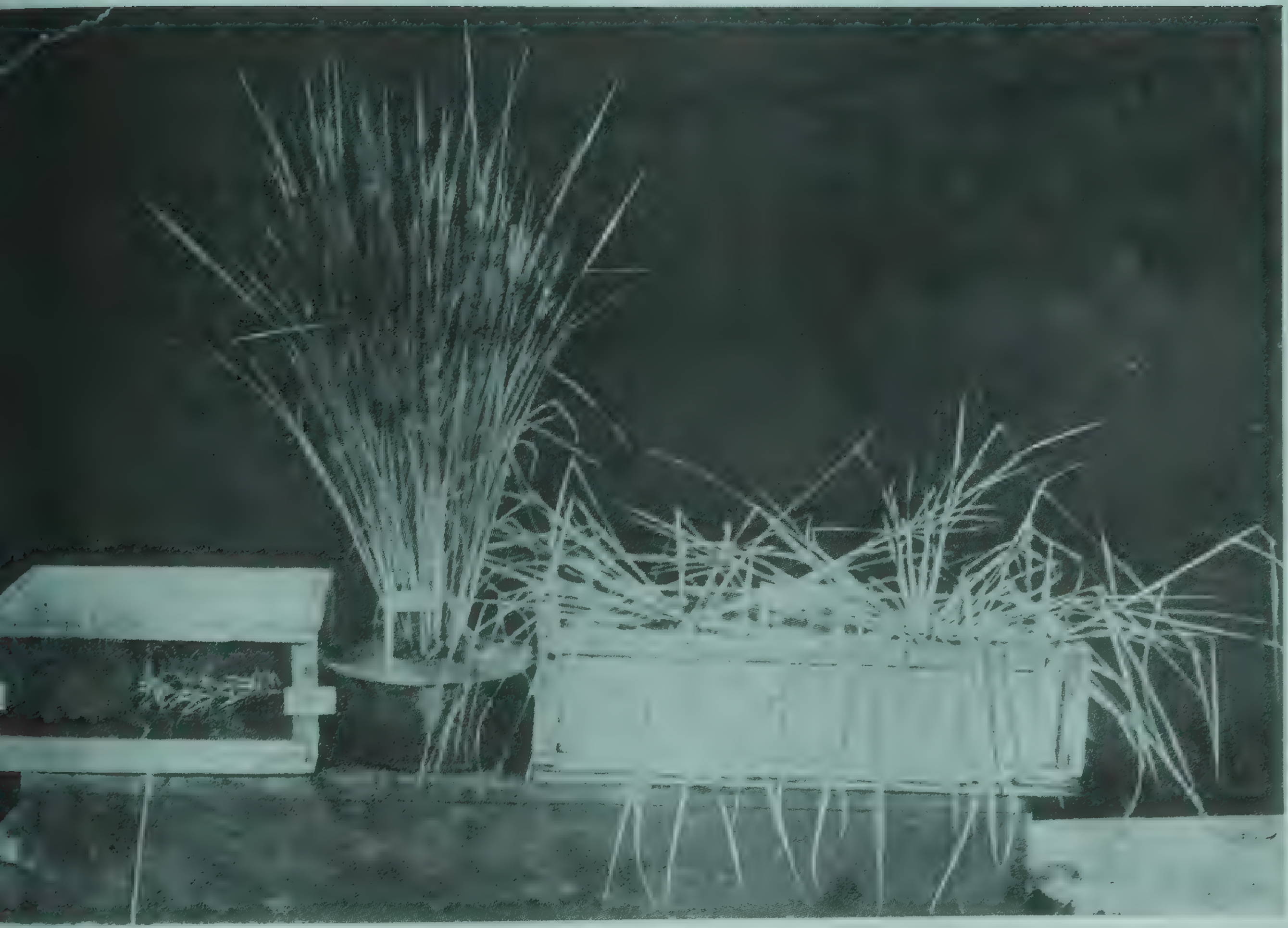
(2) *Floating habit*

A particular class of rice known as deep water or floating rice is to be found in Bengal and Assam in places which are flooded by the gradual rise of water in the fields up to 20 feet and above during the monsoon. Even where the ideal deep water conditions are not present, these varieties show the characteristic habit; the tillers in the outer zone of each clump first start trailing on the water surface and the plant shows a tendency to topple over, and at a later stage all the tillers come down flat on the surface of water (Plate XII). This diagnostic habit was utilised by Ramiah and Ramaswamy [1941, a] to study a cross between floating and normal rice without the deep water conditions. In the F_2 generation, a segregation of 15 normal to 1 floating habit was obtained and the F_3 results confirmed the F_2 behaviour. There was no genetic association between floating habit and plant height. The floating habit is controlled evidently by duplicate recessive genes which may be designated **ef**$_1$ and **ef**$_2$.

(3) *Dwarfism or dwarfness*

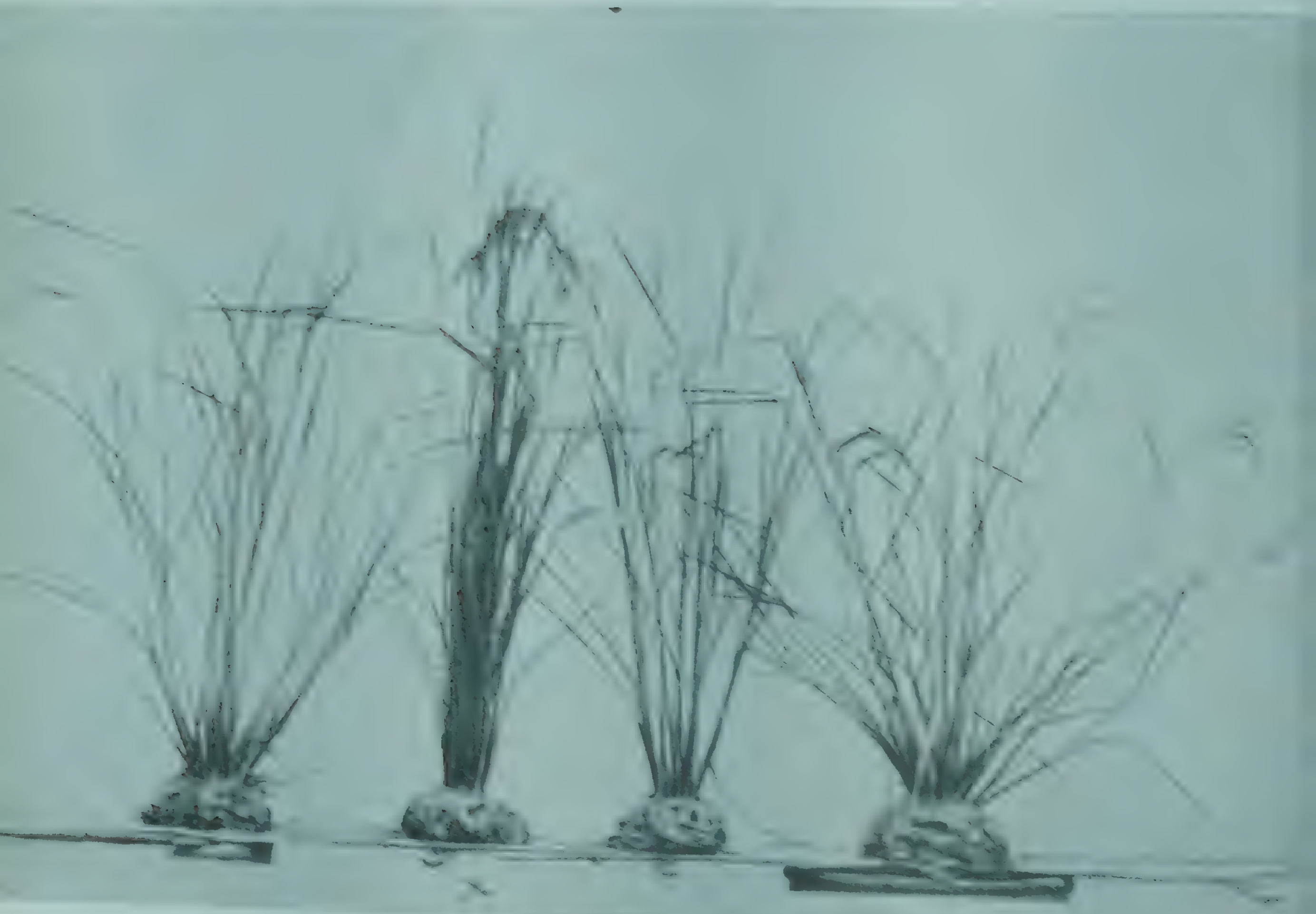
A review of the available literature would show that dwarf habit in rice is governed by specific genes in the organism. The occurrence of dwarf plants, on the analogy of results obtained in other crops, may be either due to gene mutations or changes in the number of chromosomes. There is, of course, a wide variation in the normal height of the several pure breeding varieties, height being governed by multiple genes. In crosses among such types, plants may occur with considerably diminished heights compared to the parents due to interaction of genes but these cannot strictly be called dwarfs. The typical dwarfs, however, occur as mutations either

Ageotropic Mutant


nal
ing
Ageotropic
seedling
Normal
plant
Ageotropic
plants (134 days old)

(After Ramiah & Parthasarathy 1936)

P



F2—Variation in habit. (X=Compact)

(After Ramiah I

spontaneous or induced. Some of these mutations have become stable and fully fertile and been recognised as varieties while others are sterile and unstable. While the inheritance of height is described elsewhere, the genetics of dwarfs is described in the following paragraphs.

(a) *Established 'dwarfs'*. Parnell *et al.* [1922] studied a dwarf type originally obtained from Burma in crosses. This dwarf was a simple recessive to the normal. The special feature of this dwarf is that several other characters like, stiff erect stem, broad coarse leaf and a compact stiff panicle with small grains, etc., all went together with the dwarf habit, evidently the pleiotropic effect of the dwarf gene. Yamaguti [1929, a] has reported of a dwarf of similar nature.

(b) *Dwarfs arising as mutations*. In an F_3 progeny of a cross, Ramiah [1934] observed a few dwarfs about 2 feet in height while the parents were over 3 ft. 6 in. in height. In the next generation out of three normal plants, two bred true while one threw out a few dwarfs. Of two dwarfs that were grown, one was pure dwarf whereas the other threw out a few normals. Further work showed that some normals in segregation gave varying ratios of normal to dwarf, from 2 : 1 to 6 : 1. Self sterility was probably upsetting the normal ratio of 3 : 1. It would appear that the first dwarf arose as a recessive mutation in the F_1 generation. The dwarfs throwing out a few normals may be due to a reverse mutation.

In another cross one F_3 progeny gave a single dwarf and this dwarf when isolated bred pure showing that the recessive gene mutation had occurred simultaneously in both the homologous chromosomes. The occurrence of similar dwarfs has been observed by Kadam [1932] and Dixit [1942].

Ramiah [*loc. cit.*] obtained three seeds from a highly sterile cross progeny which later was found to be a triploid. Of the three plants obtained two were very short and completely sterile while the third was tall and fertile. Cytological study showed that the two dwarfs had $2n = 27$ and 28 chromosomes respectively, while the fertile plant had $2n = 25$.

Kadam [1937] has studied crosses between normal and dwarf types from India, Japan, the United States of America and Australia and suggested that there are five genes d_1 to d_5 all recessive to the normal *D* and that the gene d_2 was the most common in these varieties.

While dwarfs are all recessive, Sugimoto [1923] reports of a case of dwarf mutation having a dominant nature. Akemine [1925] describes three dwarfs 60 cm., 20 cm. and 22 cm. high respectively. Types 1 and 2 behaved as recessives to normal and when they were crossed produced a normal F and the F_2 gave 9 : 3 : 3 : 1 of normal to the three types of dwarfs mentioned above. Nagai [1926] mentions the case of a recessive dwarf of mutational origin but the percentage of dwarfs gradually increased in subsequent generations and tending towards equality of normal and dawrf. Imai [1936] has reported of a case with remarkably low ratio of dwarfs. same as the case mentioned by Ramiah and he has explained that the low ratio was due to the gametophytic competition, the chances against the dwarf gamete contributing to the fertilization being calculated as 11.5 to 1. Piacco [1939, b] mentions the case of an extremely dwarf mutant occurring in a cross between two established dwarf races, *Nanetto* and *Nano*.

(c) *Induced dwarfism.* Ichijima [1934], Oryoshi [1936] and Ramiah and Parthasarathy [1938] record the occurrence of many dwarf mutations in X-rayed rice. Several of these mutations had also other parts of the plant affected and often associated with poorly developed heads and spikelet sterility. Nakayama [1939, 1942] made a detailed study of the growth limiting effects of some of the genes responsible for dwarf habit, and found that while the genes inhibited the growth of the stem, lemma and palea they did not have any effect on the reproductive organs. Further studies by him on the development of the panicle revealed that the development of greater length in normal types was due to more active cell division and not to larger dimensions of the cell.

The genetic relationship of the different types of dwarfs would constitute an interesting study. It would appear that the size of different plant organs is positively correlated as if determined by the same gene, except probably the grain size which as Adachi [quoted by Nakayama, 1939] reports may be determined independently of the size of the vegetative organs. No definite relationship has been observed between dwarfism and sterility, but wherever the latter occurred, it was mostly male sterility. The dwarf plants are generally weak physiologically and Yamazaki [quoted by Nakayama, 1939] had shown them to germinate better in potassium chlorate solution thereby indicating that they may be more drought-resistant than the normal type.

(C) *Abnormal habits*

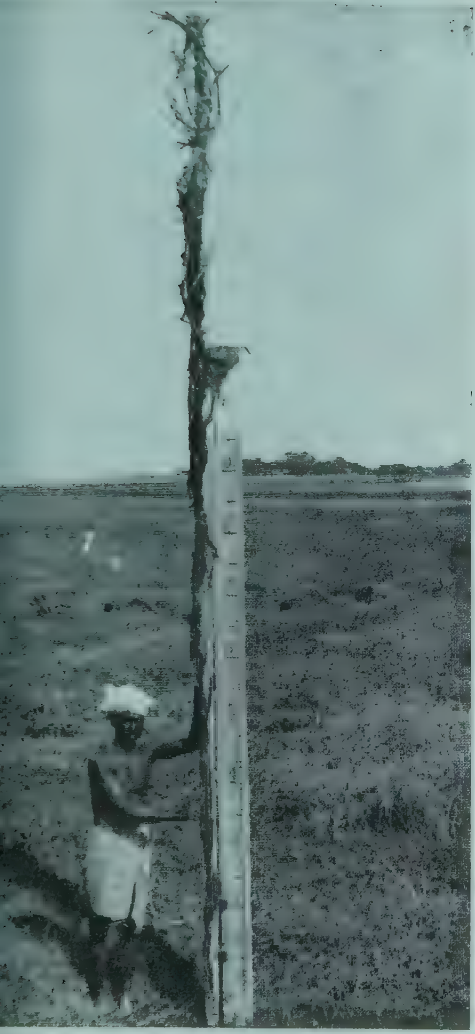
Imai [*loc. cit.*] obtained a *slender* mutant, a somewhat etiolated and non-viable form, which behaved as a recessive to the normal but with a very low proportion of the recessive. The proportion, however, increased from 3 to 15 per cent in subsequent generations. This peculiar behaviour was ascribed by him to disharmony between the plasm and the gene which, however, decreased in later generations owing to the adaptability of the plasm. A number of different types of abnormal plants distinct and constant, was obtained at Coimbatore by treating the rice seeds with X-rays [Ramiah and Parthasarathy, 1938]. A mutant called *stumpy* was characterised by close arrangement of leaves, stiffness of straw, absence of drooping habit in the panicle, and a certain amount of sterility. The character was a simple recessive to the normal habit. Other mutant types, *barren*, *vigorous sterile*, and *weak sterile* showed characteristic differences from the normal habit of the plant and these are described elsewhere.

(D) *Internode*

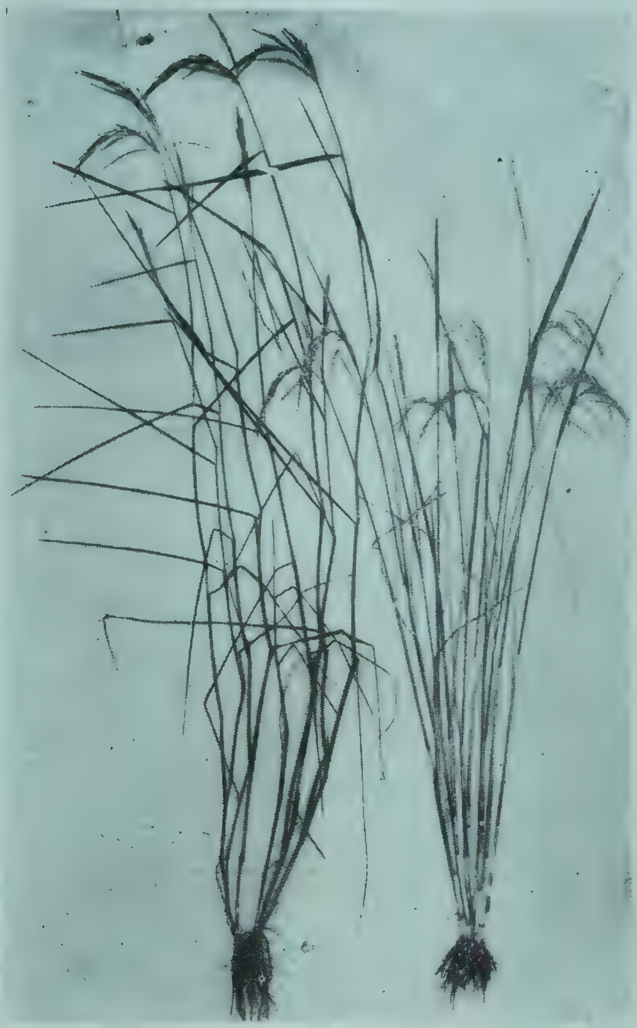
(1) *Colour*

Besides the two main colour types, green and yellow (gold), the latter always associated with gold colouring of lemma and palea, there are others with anthocyanin pigment in internodes. There is a good deal of variation in the position and intensity of anthocyanin clour, from the faint purple lines developing only when the internode is exposed to light to the almost red and black forms where the whole internode is involved. The pigment may be confined to the vascular bundles and appear as lines or it may spread into the surrounding cortex tissue giving the appearance of self colouring (Plate XIII).

PLATE XII



Deep water rice. Assam.

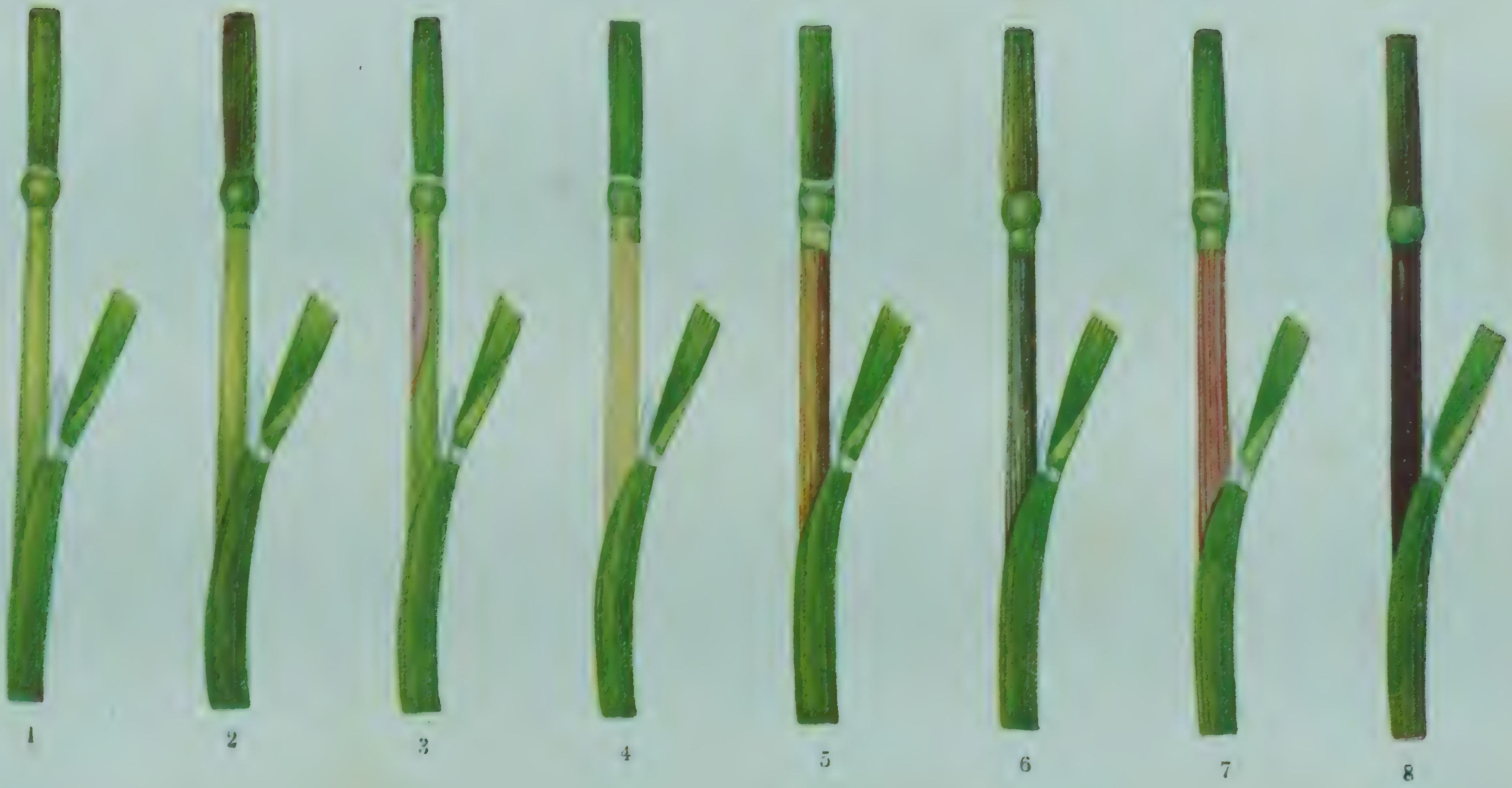


Deep water rice Normal rice

Family segregating for the floating habit
(After Ramiah and Ramasamy. 1941a.)

Plate XIII

INTERNODE COLOURS



(i) *Purple*. Various types of segregation for anthocyanin colour have been obtained in crosses with different varieties. Hector [1922] and Mitra *et al*. [1928] obtained a monogenic difference between presence and absence of anthocyanin in some crosses. Hector [1922], Chao [1928, a] Mitra *et al.* [1928] and Ganguli [1942] obtained also a 9 : 7 ratio of purple to green in some other crosses. Ratios of 27 : 37 indicating the presence of three genes for production of colour were also obtained by Hector [1922] and Jones [1930, a]. Hector did not differentiate between self colour and colour in vascular bundles but from the plates he has given, it would appear most of the patterns have self-colour. The above ratios may be explained with the help of a localisation gene **Ntp** which acting along with the two basic anthocyanin pigment genes **A** and **C** is responsible for the three types of segregation recorded above. The 27 : 37 ratio will be produced when the parents differ in the three pairs of genes. When each of the parents differ in two of the three genes, the F_2 segregation will be of the form 9 : 7.

Parnell *et al*. [1917] had studied the purple lining of the internode and found many gradations in the colour and they were of the opinion that a number of modifying factors might be concerned in the intensity of the purple pigment; they did not however pursue the study as it was considerably complicated. The actual type of lining, however, did not matter as all of them behaved in the same manner showing a single gene difference over no colouring which was recessive. Thus the gene for purple lining may be designated **Ntv**.

At the Paddy Breeding Station, Coimbatore, (unpublished records) crosses were made between different types of internode colouring and the results are given below :—

(ii) *Self-purple × purple lining*. The F_1 was a self purple but the colour was a little lighter than in the parent. The F gave a ratio of 3 self : 1 lines, showing a single gene difference.

(iii) *Self-purple × green*. The F_1 was self but less intense than the self-parent. The F_2 gave a ratio of 9 self-purple : 3 purple lines : 3 light purple lines : 1 green.

(iv) Another interesting cross studied at Coimbatore (unpublished records) about the depth of anthocyanin pigment on the vascular bundles of the internode may be mentioned here. Two varieties, one with very dark purple lining (almost bluish black, grade 6 of Plate XIII) and another with ordinary reddish purple lining were crossed. The F_1 had only ordinary purple lining and two F_2 families were grown. The internode was classified according to the depth of colour in the lining and the following ratios were obtained :

		Calculated 12 : 3 : 1
Ordinary purple lining of various degrees	1963	1980
Medium dark purple lining definitely less in intensity than in the parent ...	492	495
Very dark purple lining as in the parent ...	183	165

The inheritance can be explained with the help of two genes A and B, one dominant over the other, the ordinary purple lined parent carrying both the genes and the dark lined parent neither. The F and F behaviour was found to confirm the above hypothesis.

Mitra *et al.* [1928] have recorded other peculiar cases which are given below :

In a cross between two green internodes, the F_1 was light purple and the F_2 gave a 3 : 1 ratio of green to light purple. This has been explained on the basis that the light purple was due to the heterozygous condition of two genes, all other combinations giving green. The explanation must be considered unique. The ratios given by them, however, give a good fit to a 13 : 3 of green to purple indicating that an inhibitory factor is possibly involved. In a second cross between green and purple internode the F_1 was light purple and the F_2 gave 9 light purple to 3 green to 4 light brown. In a still third cross between green and light brown internode (gold) the F_1 was light purple and the F_2 gave 9 light purple to 3 green to 4 light brown.

The authors did not offer any hypothesis to explain these ratios. Matsura [1933] has, however, explained them on the following scheme.

P (A B)—Purple.
p AB—Light green.
p A b—Green.
p a (B)—Light brown.

In the case of cross two above, two genes **P** and **A** are involved ; **P** for green and **A** for purple which is epistatic to the former, the double recessive being light brown. In cross three, the results would indicate that two dominant genes **A** and **B** together produce light purple, gene **A** only green and either **B** or none light brown.

(v) *Green* × *Gold.* Crosses between the gold and green internodes show that the gold is a simple recessive to green [Parnell and others, 1917]. It may be mentioned that the gold colouring of the internode was associated with the gold colouring in the lemma and palea ; separate genes cause gold colour in the internode and lemma as some crossovers are met with. The gene governing the gold colouring in internode may be designated **Ltpr** green being **ntp**.

(2) *Other characters of internode*

(i) *Thickness.* The physical characters of the internode vary a great deal. Though the stems of many varieties are hollow, some rice varieties have less hollow internodes, i.e. they possess a thicker rind and this may help to prevent damage by wind, keeping them erect. There is also a great variation in the diameter of the stems. Obviously the stouter the stem, the greater is its resistance to adverse atmospheric conditions. No inheritance studies have been made on the physical characters of the rice stem in India. Kato according to Ikeno [1919] obtained in an F_2 of a cross between a thick and thin stem a continuous range of thickness indicating polygenic inheritance.

(ii) *Brittleness.* Jones [1933] studied qualitatively a cross between a variety with extremely brittle leaves and stems and a normal variety and obtained a ratio of 3 normal to 1 brittle in the F_2 generation. The gene controlling brittleness of culm may be designated as **be**. Chemical analysis did not give any clue regarding the cause of brittleness, and it is believed that it may be due to a peculiarity either in cell structure or cell arrangement.

(iii) *Bending at nodes.* In certain varieties of rice the culm is slightly bent at higher nodes in an L shape. This feature was studied at the Paddy Breeding Station, Coimbatore. (unpublished records). The F_1 had bent nodes and in the F_2 generation, a segregation of 9 bent nodes to 7 straight was realised showing the presence of two complementary genes **Nba** and **Nbb** causing bending at nodes.

(E) *Stem nodes*

Mitra and Ganguli [1932] obtained a monogenic difference between purple node and green node while Jones [1930, a] obtained a 9 : 7 ratio of purple to green. Lee [1927] working with Japanese varieties realised a 27 : 37 ratio of colour to no-colour in the F generation indicating the interaction of three factors for production of colour. The two basic genes **A** and **C** and another localisation gene **Np** could explain these ratios. When colour in lemma, apiculus and node were taken, a four factor ratio was obtained indicating that the two basic genes **A** and **C** were common to both the parents.

(F) *Septum*

The partition between two internodes just inside the swollen growth, called septum, varies in colour from light yellow to pink and shades of purple. It is best seen by cutting the tiller just below the second or third node from ground level and looking through the cut end. Ganguli [1942] reports the occurrence in an F_2 of a natural cross, a ratio of 9 purple, 3 yellow and 4 brown showing that two complementary genes govern the purple in the septum. In a cross between a dark purple septum and pinkish septum, the F_1 was dark purple, and in the F_2 there was obtained a 3 : 1 ratio of dark purple to pink, a single gene difference. In another cross between a dark purple septum and one without any anthocyanin pigment, the F_1 had dark purple septum and in the F_2 a dihybrid ratio was obtained namely, 9 with dark purple septum, 6 with light purple septum and 1 with no pigment showing that two genes were involved (unpublished records of Coimbatore). The presence of colour in the septum is often associated with the presence of such pigment in internode, lemma, palea and stigma and more particularly with that of internode.

3. LEAF CHARACTERS

The leaf in the grass family consists of the leaf sheath, the axil of the sheath, the junctura at which is attached the leaf blade to the sheath, the ligule, the auricle and the leaf blade proper. The inheritance studies made in each of these are detailed in order.

(a) *Coleoptile*

The colour in coleoptile, the first leaf, which may show shades of purple is always associated with some colour in the leaf blade or lemma and palea. But its segregation does not seem to have been studied in detail so far. Chakravarty (unpublished records) obtained a 3 : 1 ratio of coloured to colourless coleoptile though the fit was not good. The gene **C** governing purple colour in the coleoptile may be the same as the one causing pigmentation in the sheath.

(b) *Pulvinus*

The colour of the pulvinus varies from a few purplish spots to a black (concentrated purple) girdle on the stem. Purple colour in pulvinus is dominant to the green condition and a ratio of 3 colour to 1 green has been obtained by Parnell *et al.* [1917]. The simple dominance of colour has also been observed by Mitra and Ganguli [1932] and Van der Stok quoted by Matsuura [1933]. Hector [1922] and Mitra *et al.* [1928] have obtained a 9 : 7 ratio also indicating the presence of complementary genes. The 3 : 1 and 9 : 7 ratios can be explained by supposing a localisation gene which acts in conjunction with the two basic genes **A** and **C** for purple colour. Van der Stok quoted by Matsuura obtained also a 15 : 1 ratio. Two duplicate genes are assumed and it is possible that one of these may be identical with the localisation gene.

(c) *Leaf sheath*

The common colours noted are green and purple of various grades. In the purple, the colour is more pronounced on the sides and edges. Apart from the intensity, the colour varies also in the position, viz. (1) only the parenchymatous tissue may be coloured or (2) the vascular bundles alone may be coloured or (3) both these may be coloured (Plate XIV). The green may be light or dark in depth but it is difficult to distinguish the grades in green from plant to plant. In some cases the colour is present only in the axil inside the leaf sheath and green outside giving a false presence of colour. In many of the inheritance studies no difference appears to have been made out in the intensity and location of the purple colour.

(i) *Self colour.* Hector [1922] has observed in crosses between different varieties that the presence of colour irrespective of its position was always dominant to its absence and ratios of 3 : 1, 9 : 7, 27 : 37 and 15 : 1 of purple to green occurred in F_2. These ratios have also been recorded by several other workers, Van der Stok quoted by Matsuura [1933], Parnell *et al.* [1917], Roy [1921], Mitra *et al.* [1928], Chao [1928, a] and Ting [1933]. It would appear that at least five genes are concerned in the segregations noted above. Taking the two basic genes **A** and **C** necessary for the production of colour, a localisation gene **Lsp** in combination with the above would give a 27 : 37 ratio. The 9 : 7 ratio is obtained when each of the parents differ in two of the three genes.

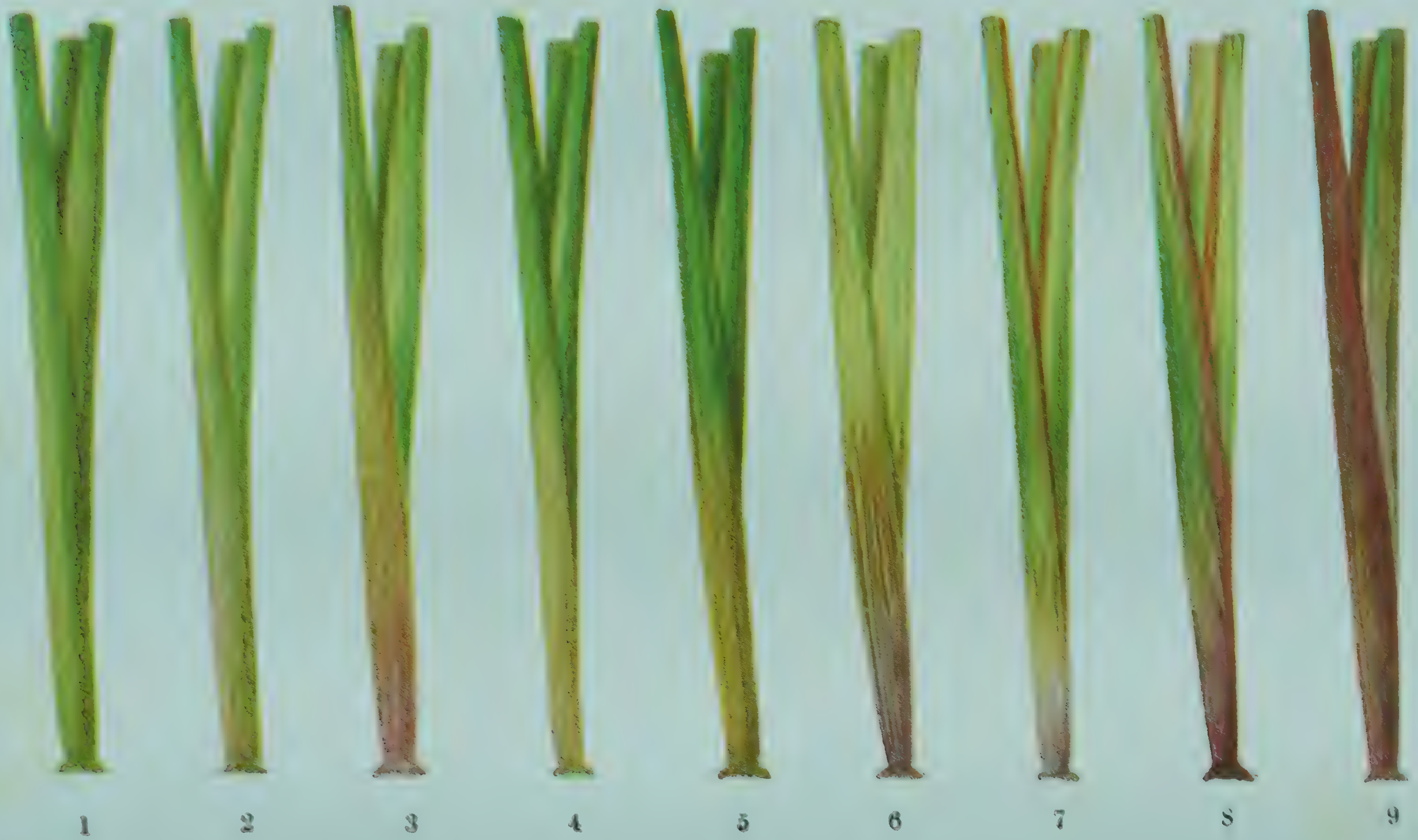
When the parents differ only in one gene, the 3 : 1 ratio is obtained. Two duplicate genes **Lsp$_1$**, **Lsp$_2$** cause the 15 : 1 ratio.

(ii) *Purple lines.* Jones [1930, a] obtained in an F_2, a ratio of 27 purple, 9 purple striped, and 28 green leaf sheaths. These results he explained on a three factor hypothesis all the factors being necessary for purple and two of them only for the purple striped and all the rest of the combinations giving green.

Unpublished records of the Paddy Breeding Station, Coimbatore, deal with some crosses involving sheath character. A cross between purple lined sheath and a green one gave a simple segregation of 3 : 1 of purple line to green showing a single gene difference. Another cross between a type with both purple self colour and lines in the sheath and a green gave a dihybrid segregation in the F_2: 9 self purple with lines, 3 self colour only, 3 lines

Plate XIV

SHEATH COLOURS



only and 1 green. Evidently the self colour and lines are controlled by different genes. The gene for purple lines is a simple dominant over green and may be designated **Lsv**. There are reasons to believe that there is some interrelationship between lining in the sheath and lining in the internode. In the latter cross mentioned above where there was segregation for the depth of lining in the internode, one with very dark lines and self colour, almost looking blackish and the other with ordinary purple lines only, the latter type did not occur where the sheath either did not have purple lines but had self colour only or remained green.

(iii) *Striping.* Roy [1921] has observed striping in leaf sheath which has later been recorded also by Ramiah and Parthasarathy [1938] in X-rayed material. Pal and Ramanujam [1941] obtained leaf sheath striping in a mutant associated with variegation in leaf blade. In inheritance, the striping is a simple recessive to the normal.

(d) *Leaf axil*

The colour in the axil which is inside the leaf sheath is intimately associated with that of colour in the stigma and this led the earlier workers to believe that the same gene or genes were responsible for the presence of colour in both these parts. But later studies have shown that the genes are independent as some crossovers with white stigma and purple colour in the axil were obtained. Presumably the genes are very closely linked. While the presence of colour in the axil has generally proved a simple dominant over its absence, there was one cross (unpublished records of Coimbatore) where dark purple axil proved a simple dominant to light purple axil, the depth of colour in the stigma in this case going along with the colour of the axil. Evidently dark purple, light purple and green are allelomorphs.

(e) *Junctura*

Colour in the triangular portions where the blade is attached to the leaf sheath (described wrongly as pulvinus by some authors) varies from a few purple dots on the margin to an intense purple almost appearing black. Parnell *et al.* [1917] found almost complete linkage between colour in junctura and auricles without obtaining even one crossover in large populations of a cross between a coloured and a non-coloured junctura. The presence of colour behaved as a simple dominant over its absence. There was also additional evidence of the presence of complementary genes for the presence of colour, there being obtained also a 9 : 7 ratio of colour to no-colour. Jones [*loc. cit.*] realised 9 : 7 and 27 : 37 ratios of coloured to non-coloured junctura. The 3 : 1 ratio is obtained when the two parents differ only in the localisation gene **Jp**. The 27 : 37 ratio represents the result of the segregation of the two pigmentation genes **A** and **C** and the localisation gene, and 9 : 7 ratio results when each of the parents differ in two of the three genes.

(f) *Auricles*

Arising on either side of the attachment of leaf blade to the sheath are two linear ciliate bodies clasping the stem. The length of the auricles varies in individual varieties.

(i) *Auricleless.* Jones [1933] and Chiapelli [1936] obtained a mutation without auricles which behaved as a simple recessive to the auricled condition and this may be designated **au**. Studies at Coimbatore (unpublished records) of a cross between an auricled and an auricleless variety gave, however, in the F_2 a complicated segregation, the size of auricles varying from the normal to no auricle without conforming to any definite ratios.

(ii) *Colour*. Mitra *et al.* [1928], Mahta and Dave [1931] obtained a monogenic segregation of colour to no-colour while in Hector's [1922] material and in the wild rice natural cross of Mitra and Ganguli [1932], colour was conditioned by two complementary genes giving a ratio of 9 : 7 of colour to no-colour. Jones [1930, a] obtained 9 : 7 as well as a 27 : 37 ratio of purple to no purple indicating the presence of two and three genes for colour. Fruwirth [1908] realised a 15 : 1 ratio of purple to non-purple. Unpublished records from the Paddy Breeding Station, Coimbatore, would appear to indicate that the ordinary coloured purple auricle is governed by one dominant gene and that an additional gene makes the colour darker. A ratio of 15 : 1 between purple auricle and green auricle and 3 : 1 between dark purple and light purple or between light purple and green have been recorded. Other workers have, however, not differentiated the depth of colour in the auricle. Taking into consideration the basic genes **A** and **C** for producing anthocyanin colour, the duplicate localisation genes $\mathbf{Aup}_1$ and $\mathbf{Au}_2$ gave the 15 : 1 ratio, when either of them is absent in one of the parents a 3 : 1 ratio is obtained. The interaction between the two pigment genes and the localisation gene **Aup** could give either 27 : 37 or a 9 : 7 according to the constitution of the parents.

A case of colour in auricle being recessive has been reported by Mitra and Ganguli [*loc. cit.*] in a cross between a wild and a cultivated variety of rice both of which had green auricles. The F_1 was also green but in the F_2 a ratio of 15 green auricles to 1 light purple was realised. This would indicate the presence of duplicate inhibitory factors each of which is contributed by one parent. It cannot be said for certain whether the green mentioned by the authors was really green, because it has been observed at Coimbatore that in some of the varieties, more particularly in the wild types, the colour can be present in an extremely dilute form not easily made out by the naked eye.

(g) *Ligules*

The papery extension of the sheath called ligule helps to keep the leaf in a bent position to receive light and its size varies in different varieties.

(i) *Liguleless*. Almost all cultivated varieties have the ligule. Jones [1933] has, however, recorded a variety without ligule, and the liguleless condition behaved as a simple recessive to the normal. According to Ikeno [1919] Kato had also obtained a similar result. A mutation without ligules was obtained by Chiapelli [1936]. The liguleless condition may be designated **lg**.

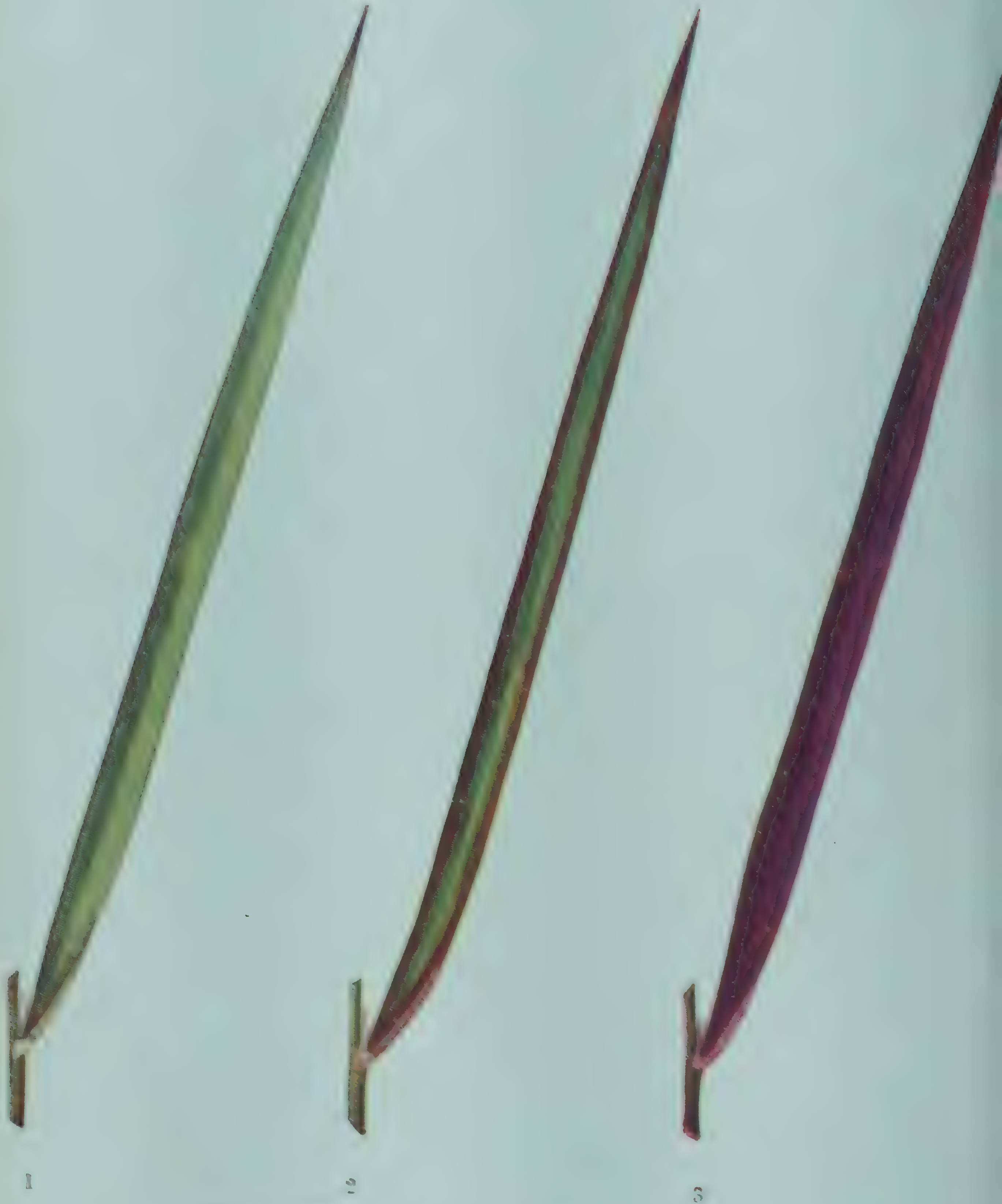
(ii) *Colour*. The colour in the ligule varies from a few purple specks or splashes to completely purple all over. The following segregations have been recorded between purple coloured and white ligule but no information is, however, available as to the intensity of the colour.

3 : 1 —Hector [1922], Mitra *et al.* [1928], Mitra and Ganguli [1932], Mahta and Dave [1931], Ramiah (unpublished records).

15:1 —Ramiah (unpublished records).

Plate XV

LEAF BLADES



(HUTCHINSON & RAMIAH, 1938.)

9 : 7—Hector [1922], Mitra and others [1928], [1930, a].

27 : 37—Hector [1922], Mitra and others [1928], Chao [1928, a], Jones [1930, a].

As indicated for other characters where similar ratios have been obtained a localisation gene, designated **Lgp** interacting with the two pigmentation genes is responsible for the different types of segregation.

(h) *Leaf blade*

(1) *Colour*

(i) *Purple.* Besides the normal green, several types of anthocyanin colouration in the leaf lamina can be distinguished. They may be roughly grouped into three classes as below. In one, the pigmentation is confined to the tip and margins of the blade, in the second this colour slightly spreads down from the tip and also inside from the margins giving up appearance of purple wash and in the last the whole leaf blade is deeply pigmented (Plate XV). The last group, however, occurs very rarely and there has been only one type of this in the Coimbatore collections. In segregating families we get grades of purple somewhat intermediate between the above three types but it has always been found difficult to classify them separately. Deep colour of leaf blade in the type growing at Coimbatore is found associated with a similar colour in lemma and palea. It is, however, possible to find other such deeply pigmented types but without colour in the lemma and palea. In the reported results of many of the workers there has been no attempt made to distinguish either the intensity or the distribution of the purple colour in the lamina but all plants which had some colour in the lamina have been grouped as purple. The following types of segregation in leaf blade colour have been recorded :

3 purple : 1 green Parnell *et al* [1917]. Kato quoted by Matsuura [1933], Nakayama [1935].

9 purple : 7 green Parnell *et al.* [1917], Jones [1930, a]. Sethi [1934], Kato quoted by Matsuura [1933].

27 purple : 37 green [Takazaki, 1923].

3 purple : 13 green Kadam [1936, a]. Yamaguchi [1937]. Dave [1938].

15 purple : 1 green, Ramiah (unpublished records).

3 green : 1 purple, Dave [1938].

The ratios of 3 : 1, 9 : 7 and 27 : 37 of purple to green can be explained with the help of a localisation gene **Lp** which interacting with the two basic colour genes **A** and **C** can produce these ratios.

The ratios of 13 green to 3 purples in F_2 generation obtained by Kadam [1936, a] and Dave [1938] were from crosses between two different green leaf parents and an identical full purple leaf parent, *Nagkesar* by name. The behaviour of F_3 progenies confirmed the F_2 ratios in both the cases. This F_2 ratio should indicate the presence of an inhibitory factor; since the green leaved parents had anthocyanin colour in other parts they carry an inhibitory gene **Ilp** which suppresses the production of colour governed by factor **Lp** in the leaf lamina.

Sethi [1934] has studied different sets of crosses between types with purple and green lamina. In one cross, the purple lamina was dominant in F_1 and the F_2 gave a 9 : 7 ratio of purple to green. In another cross, the absence of colour was dominant in F_1 and in F_2 and anomalous ratio of 1 purple to 10 green was obtained. Seventy nine families of this cross studied in the F_3 generation showed ratios varying between 1 : 1 and 1 : 9 of purple to green. The author has suggested the interaction of three genes but it would appear that some linkage phenomenon must be at work to produce these anomalous ratios. Further crosses are still said to be under study and nothing can be said definitely until these results are available. A very similar case has also occurred in Bengal in a cross between a variety with purple lamina and another with green lamina. Chakravarty [1940] obtained a ratio of 8.3 : 1 of green to purple in F_2 . In subsequent generations the ratios of green to purple were found to vary between 4.5 : 1 and 9 : 1. Whether these aberrant ratios are due to any linkage is under investigation.

Yamaguchi [1938] presented evidence in some crosses that in addition to three genes concerned in the production of colour in lamina, there was an inhibitory gene **Ib** which either in homozygous or heterozygous condition makes the colour light, **ibid** plants alone being dark purple.

Dave [1938] crossed the same purple leaved parent, *Nagkesar*, with two green leaved parents other than the one which gave him 13 : 3 of green to purple mentioned previously. The F_1 was green in both the crosses but the F_2 ratios which were assumed to represent a 3 : 1 of green to purple did not give a good fit. The study of the F_3 generation, it is stated, has confirmed the simple dominant nature of green, all purple plants of the F_2 generation breeding true in F_3. While it is possible that the two green leaved parents did not carry an inhibitory gene as was the case in the cross, where a 13 : 3 of green to purple was obtained, this would still be a unique case where the presence of colour is recessive to its absence. The results would require confirmation.

Jones [1930, a] obtained in a cross between entire purple lamina and green lamina an F_1 with purple striped leaves which gave in the F_2, 27 full purple : 9 purple striped : 28 green. He has explained, the results on a scheme of three genes **A**, **B** and **C**, the simultaneous presence of all three making the lamina full purple, absence of **A** (gene for full expression of purple) making it purple-striped and all other combinations resulting in plants with green lamina.

Alam [1938] crossing an entire purple lamina with a green one obtained an F_1 which was intermediate in colour and the F_2 gave 39 F_1 type : 9 full purple type : 16 green. He has explained the results on the basis of 3 genes of which one is an inhibitor reducing the intensity and distribution of the pigment.

Ramiah (unpublished records) studied a cross between a full purple leaf and a green leaf and obtained an F_1 with reduced amount of purple in the lamina. In the F_2 classification, the total greens formed only a small fraction of the entire population. Four groups could, however, be made out definitely, namely (i) the full purple leaf as in one of the parents, (ii) purples of varying intensities all showing purple at the tip and margin and also in the body of the leaf, (iii) purple only at the tips and margins.

and (iv) green corresponding to the other parent. A large number of plants was selected and grown as F_3s. On the basis of F_3 data it was possible to explain the F_2 behaviour with the assumption that three genes $\mathbf{P_1}$, $\mathbf{P_2}$ and $\mathbf{P_3}$ were involved. $\mathbf{P_1}$ by itself shows slight purple in the body of the blade while $\mathbf{P_3}$ by itself restricts the pigment to the tips and margin only of the blade, and $\mathbf{P_1}$ and $\mathbf{P_3}$ together give full purple. Another gene $\mathbf{P_2}$ acts as a reducer acting both when $\mathbf{P_1}$ and $\mathbf{P_3}$ are together present and also where $\mathbf{P_1}$ is alone present. According to this hypothesis the F_2 should give the 4 groups in the proportion of 9:39:12:4, which agreed with the actual results obtained. Evidence that the above interpretation is correct was obtained in another cross (unpublished records) where the above full purple type was crossed with another green leaf parent. The F_1 had a reduced amount of purple on the lamina and in the F_2 three groups were made out as shown below :

	Full purple leaf and those corresponding to F_1	Purple at tip and margin of leaf blade	Green	Total
Totals of 5 F_2 families	1,387	385	122	1,894
Cal. 12 : 3 : 1	1,421	355	119	1,894

The examination of results so far available would appear to show that there should be two localisation genes **Lp** and **Lmp** to produce a full purple lamina. **Lp** by itself produces a slight purple and **Lmp** by itself produces colour at tip and margins which may be the same as $\mathbf{P_3}$ postulated by Ramiah. Some of the green types may carry an inhibitory gene **Ilp** which would suppress the action of the localisation genes giving a 13 green to 3 purple in crosses with full purples. The only inexplicable result is that obtained by Dave where green was dominant to full purple.

(ii) *Purple leaf margin.* The purple colouration confined to the margin of the leaf is reported to be due to a single gene [Mitra and Ganguli, 1932] and this gene can be **Lmp** already postulated.

(iii) *Striping.* Purple striping in leaf has been found to be a monogenic dominant to the ordinary green condition [Nagai, 1921]. This gene may be designated as **Lv**. The occurrence of this character has, however, not been recorded by Indian workers.

(2) *Leaf size : length and breadth*

Wide variations are met with in the length and breadth of leaves. A certain amount of correlation has been found to exist between grain width and leaf width, narrower grains tending to give narrow leaved plants (unpublished records of Coimbatore). Grant [1935] has studied qualitatively the inheritance of leaf width, classifying leaves as broad and narrow (broad with a mean width of 19.8 mm. and narrow with a mean width of 13.6 mm.). The F_1 resembled more the broad leaved parent and in the F_2 no attempt was made to actually measure the width of the leaves. The two classes, broad and narrow were, however, distinguishable by eye pudgment in the field crop and an approximate 3 : 1 ratio of broad to narrow was obtained, though the fit cannot be considered good.

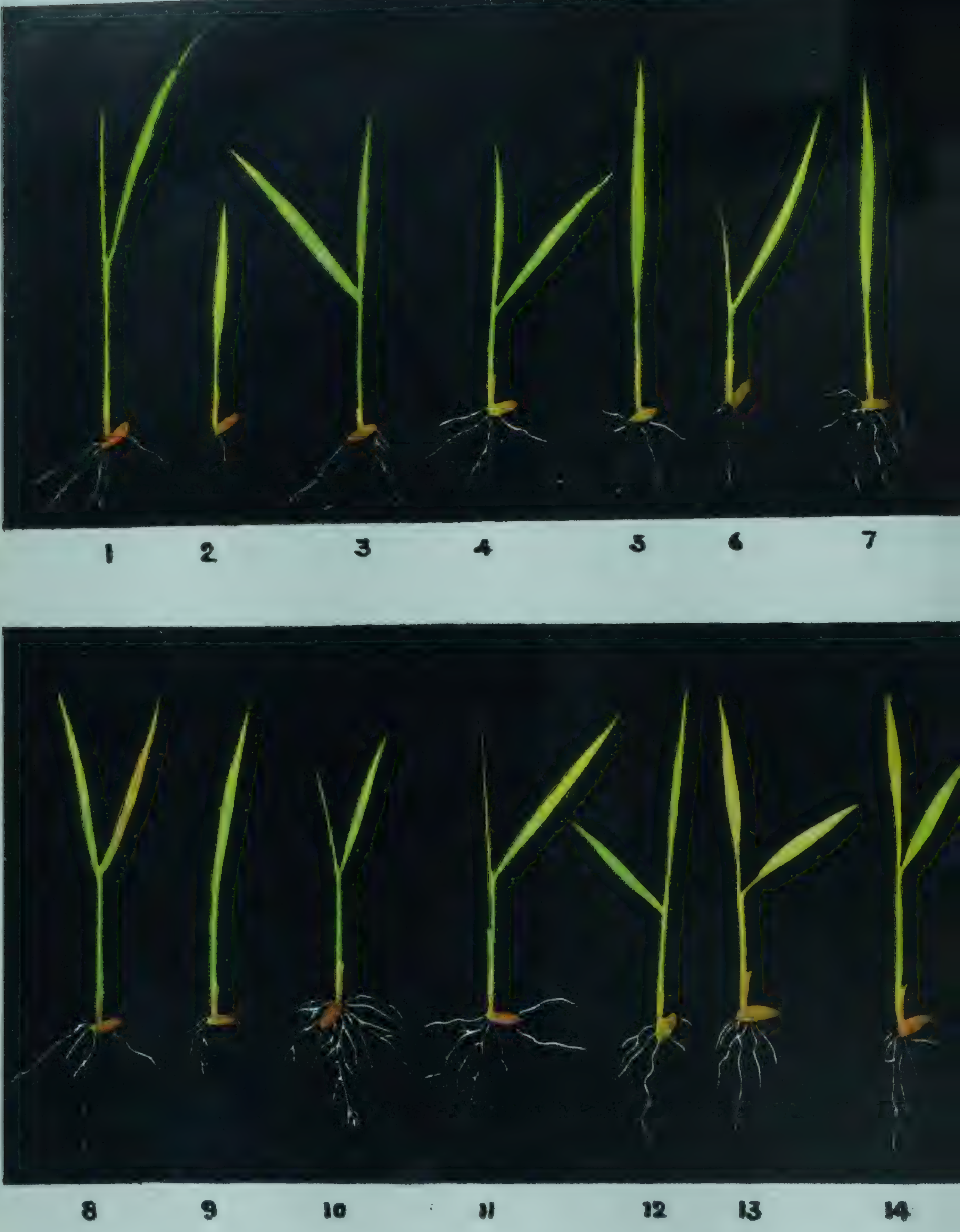
In Coimbatore, Ramiah [1934] studied the length and breadth of leaves in the parents and the F_2 generation of a cross between them. From a large number of measurements of plants within each culture it was found that the third leaf from the top in one of the main tillers was the most constant for taking measurements in each culture. The F_2 frequencies gave a normal curve with a large coefficient of variation. The coefficient of correlation between the width of F_2 parent and mean width of F_3 progeny was $+0.52 \pm 0.07$. Due to the occurrence of sterility in this particular cross, the population in the F_1 and F_2 generations was rather small and no definite ratios nor the number of genes involved could be determined. The fairly high correlation between F_2 and F_3 would however indicate that the number of genes involved cannot be many.

(3) *Abnormalities in size and shape of leaf*

Certain abnormalities in the size and shape of leaf and its general configuration have been found in certain mutations. Among the mutations obtained at Coimbatore from X-rayed material [Ramiah and Parthasarathy, 1938] there was one with rolled leaf, i.e. with margins incurved forming a half cylinder with a large amount of malformed earheads having low fertility. In the X_2 progeny of this mutation, ratios approaching 15:1 of normal to rolled leaf were obtained indicating that the rolled condition is a double recessive involving two duplicate recessive genes **lro**$_1$ and **lro**$_2$ Rhind [1931] had observed a similar spontaneous mutation in his material having short narrow leaves, partly rolled, many tillered with small, sterile, awned panicles. Its inheritance was, however, not followed. Nagai [1926] has isolated a rolled-leaf-sterile mutant as well as a rolled-leaf-fertile mutant; each of these is a simple recessive to the normal condition. From descriptions of other mutants these appear different from those recorded at Coimbatore. In another X-ray mutation obtained at Coimbatore the leaves were very narrow and also small in size. The X_2 progeny of this mutation gave a 3:1 ratio of normal to narrow leaf, and this gene may be designated **In**. Isshiki [1933] obtained a spontaneous narrow leaved mutation called 'narrow leaved open lemma' the leaf defect being due to reduction in the number of veins. This was found recessive to the normal condition, and this may be designated **In**$_3$. The same worker obtained a mutant characterised by absence of medium ribs in the leaves, twisted leaf base with much sterility. Crossed to the normal, the F_2 showed a 3:1 of normal to twisted leaf which may be designed as **ltw**, Kadam [1941] obtained a plant with a twisted leaf which did not produce chlorophyll after the second leaf resulting in death of the seedling. He called it 'twisted pale green' and it was a simple recessive to the normal.

(4) *Hairiness*

The leaf of the rice plant is characterised by short hairs on either side of the lamina and the degree of hairiness is a varietal characteristic. The hairs are few and smooth to the touch in some varieties (these may be called non-hairy) and in others the hairs are many and coarse (these varieties may be termed hairy). Ramiah [1932] had studied crosses between a non-hairy variety and a hairy one; the F_1 was intermediate though more hairy than the non-hairy parent and the F_2 gave an approximate 3 : 1 of hairy to



Chlorophyll deficient X-ray mutations (Coimbatore)

1. Normal greed. 2. Albino with streaks of yellow early stages. 3. Zebra-marked white. 4 Lethal yellow I. 5. Zebra-marked yellow-lethal. 6. Albino. 7. Lutescent. 8. Blotched. 9. Striped not dwarf, sterile and awned. 10. Green-yellow streaked. 11. Green-white striped. 12. Virescent. 13. Lethal yellow II. 14. Yellow-green-striped.

non-hairy. The behaviour of 385 F_3 families, 94 of which were pure hairy, 88 pure non-hairy and 203 segregating for hairy and non-hairy, confirmed the hypothesis that the 'hairy' and 'non-hairy' formed a simple pair of allelomorphs. Sethi [1937] has confirmed the dominant nature of hairiness but his F_2 ratios, however, approached a 15 hairy to 1 non-hairy, though the fit was not good. If this ratio is correct there should be two genes **Lh**$_1$ and **Lh**$_2$, controlling hairilness and the gene giving a 3 : 1 ratio obtained by Ramiah may be due to either of these.

4. CHLOROPHYLL DEFICIENCIES IN RICE

The green and yellow pigments of rice, as in practically all plants, are contained in the special structures called chloroplastids. Normally the chloroplastids contain two green pigments, chlorophyll *a* and chlorophyll *b*, and two yellow pigments, carotin and xanthophyll, belonging to the carotinoid group. The chlorophylls are shown by several workers to be exceedingly complex chemical compounds. The nucleus and the plasm with the plastids play a part in the formation of chlorophyll. A disturbance in the nucleus and plasm will result in a disturbance of the chlorophyll formation and consequently, deficiencies may arise.

Hann [1933] in his monograph has set out a classified account of chlorophyll deficiencies occurring in many plant species. He has described the several kinds of deficiencies individually and adopted distinguishing nomenclature such as *virescens, xantha,* etc., to specify particular types. The same terminology has been followed in the descriptions that follow. It has been found that all the deficient types are recessive in nature barring perhaps a single dominant albino in maize. Non-Mendelian inheritance involving the plasm with the plastids has also been recognised in several instances. The largest number of known chlorophyll defective types has been recorded in maize in which as many as 110 genes controlling the formation and development of chlorophyll have been identified.

It may be noted that the expression of the gene controlling the chlorophyll deficient type is to a large extent dependent upon the environment and this study offers some evidence on the physiological character of the gene. It is found in barley that there is differential development of chlorophyll in the yellowish white seedling; with temperature at 5°C. there is no development at all ; at 12° to 15°C. chlorophyll develops in tips and at 20°C. the chlorophyll development is almost the same as in normal plants and some of these survive and even produce seeds. No such investigation has been made in rice.

The presence of chlorophyll deficient genes in a variety is detrimental to its normal development. Some of these genes are lethal or semi-lethal in the homozygous condition, and in the heterozygous condition make the individuals less vigorous than the normal greens. In cross-fertilised crops like maize, these deficiencies are preserved in the heterozygous condition, but in the case of self-fertilised crops like rice, this danger is less serious as they automatically get eliminated through inbreeding and the few deficiencies that do occur now and then arise mostly as mutations. The several chlorophyll deficient types are reproduced in Plate XVI.

A. Inheritance of chlorophyll deficiencies

I. *Lethal deficiencies*

(a) *Albino*. White seedlings occur very commonly in the pure line cultures of many rice workers. As already stated these are lethal in the homozygous condition and the heterozygous sometimes give striped appearance. The first case of albinism was reported by S. Morinaga in 1927 and later by several others. S. Morinaga found the albino was controlled by recessive duplicate genes giving a ratio of 15 green to 1 albino. Ramiah *et al.* [1930] and Kadam and Patankar [1934] obtained similar results. Instances in which the albino behaves as a simple recessive, giving a ratio of 3 : 1 of green to albino have also been recorded by several investigators [Morigana, 1932, etc.].

In X-ray mutations, Ramiah and Parthasarathy [1938] obtained both 15:1 and 3:1 ratios of normal green to albino. Cases of white seedling with yellow coleoptile, probably different from the pure albino, also occurred which gave both 3:1 and 15:1 ratio of normal to albino with yellow coleoptile.

Morinaga T. [*loc. cit.*] obtained also a ratio of 9:7 of green to albino indicating the presence of two complementary genes. Codd [1934] has described an albino which occurred in a ratio of 63 greens to 1 albino, involving three recessive genes. Mitra and Ganguli [1934] have reported the inheritance of white striped and albino plants, the heterozygous white striped segregating into 3 striped: 1 albino.

Besides the 3:1 and 15:1 ratios of green to white, Ramiah and Ramanujam [1935] obtained complicated ratios which did not conform to definite Mendelian ratios, similar to the results reported in maize. Imai [1934] obtained an unstable line in rice which throws out albinos in every generation. With the present state of knowledge it is not possible to determine the relationship between the several genes governing the production of albinos. That there are perhaps five or six different genes concerned in the production of albinos may be tentatively accepted and these may be designated $\mathbf{w}_a$ and $\mathbf{w}_b$ (complementary genes) and $\mathbf{w}_1 - \mathbf{w}_3$ responsible for 3:1, 15:1 and 63:1 ratios.

(b) *Xantha or lethal yellow*. Here the seedlings have pale yellow leaves, live only for seven to ten days after the germination of the seed and then perish. In two hybrid families, Ramiah and Ramanujam [*loc. cit.*] obtained a ratio of 3:1 of normal to yellow lethal showing that the latter is a simple recessive to green. Kasahara [1934] obtained a recessive dull greenish yellow mutation which was 9.11 cm. in height and had only 20 per cent chlorophyll in the leaves, and withered away in 40 days. Imai [1935, c] has also observed that *xantha* was a monogenic recessive to the green condition. Ramiah and Parthasarathy (*loc. cit.*) obtained a lethal yellow mutation in X-ray material behaving as a simple recessive. Kadam [1941] obtained both 3:1 and 15:1 ratios of green to lethal yellows in different material. The genes for the lethal yellow may be represented by $\mathbf{y}_1$ and $\mathbf{y}_2$. In maize, the *xantha* seedlings grow up to maturity and produce seed but in rice, such phenomenon has not been observed so far. One of the yellow mutations obtained by Kadam [*loc. cit.*] managed to exist for a longer time but was still much stunted and did not produce seed. It was found to be recessive and due to a single gene, but it is not certain whether it is different from $\mathbf{y}_1$ or $\mathbf{y}_2$.

(c) *Lutescent*. This is different from *xantha* in that the seedlings are normal green first, but later the chlorophyll gradually disappears and the plant ultimately dies. The only recorded cases of this mutation are by Ramiah and Ramanujam [*loc. cit.*] and Ramiah and Pathasarathy [*loc. cit.*], who obtained them as a spontaneous mutation in a pure line culture and in X-rayed material respectively counts in segreating F_2 and F_3 generations showed the simple recessive nature of the *lutescent* to the normal green. The *lutescent* gene may, therefore, be designated **L**.

It may be mentioned here that the corresponding *lutens* seedling in maize is first lemon yellow, and later turns green developing some chlorophyll but not sufficient to be viable and produce seed. The lutescent derived by Ramiah and Ramanujam corresponds to the yellow white described in maize.

(d) *Leaf tip drying*. Jones [1931] reports a characteristic tip drying nature in a pure line which is a constant feature of that variety. That it is not due to any fungus or other causes is evident from the fact that it persists more or less almost on every plant and from year to year. This character must, therefore, be considered hereditary. Kadam [*loc. cit.*] has also observed a similar case. A hybrid in *Kolamba* rice segregated into 9 normal green : 7 tip burn yellow. These yellow seedlings perish after the development of the second leaf with the tips of leaf blades withering as if due to lack of moisture. The F_3 results confirmed the complementary nature of the genes producing the tip-burn-yellow. These genes have been designated **tpa** and **tpb** by the author. Whether the 'tip burn yellow' of Kadam and 'leaf tip drying' of Jones are the same or different cannot be said.

II. *Virescent*

In certain plants there is some delay in the development of chloroplastid pigments in the seedlings so that they appear first white or slightly yellow and then gradually change to green. These are called *virescent*. A virescent yellow was first studied by Ramiah *et al.* [*loc. cit.*] who found that the character was controlled by duplicate genes giving a 15:1 ratio of green to virescent. The virescent gene may be designated **v**. Rhind [1931] has reported from Burma a 3:1 ratio of normal to virescent. Recently Kadam [*loc. cit.*] has made extensive studies with six virescent types and come to the conclusion that of the six genes controlling the virescent character five are non-allelomorphic and these have been designated $\mathbf{v}_1$ to $\mathbf{v}_5$ while the sixth which is an allele to $\mathbf{v}_1$ and higher in the series than $\mathbf{v}_1$ has been designated as $\mathbf{v}_1$. He believes that there is an unknown gene which accelerates chlorophyll formation (reaction gene) in some crosses which disturbs the normal segregation resulting in such ratios as 45:15:4 and 45:9:10 of the phenotypes. The work on these series is still in progress. Jodon [1940] reports of a virescent mutation which is a simple recessive to the normal condition and is partially linked with the genes for glutinous endosperm, colourless apiculus and clustering of spikelets in the panicle. This virescent may not be different from the other virescents.

III. *Chlorina*

The depth of chlorophyll pigment and the carotinoid pigment varies a great deal in rice varieties. Plants with all gradations from dark to light yellowish green colour occur sometimes, even in the same commercial variety. These greenish yellow forms are called *chlorina* types. It is often difficult to distinguish the depth of colour from plant to plant and no genetic studies have been made in India with regard to the depth of green colour. In a few varieties, strains with yellowish green leaf were isolated at Maruteru [Srinivasan, 1929] and these were earlier in duration and yielded better than the normal green. Morinaga, T. [*loc. cit.*], however, reports from studies of crosses between normal and *chlorina* varieties that *chlorina* is a monogenic recessive, which may be designated *chl*.

IV. *Striped patterns*

(1) *Green and white striped.* This is by far the most common of striped patterns. The first leaf is almost white with a tinge of green at the tip which later extends downwards. The second and third leaf are similar but with more of green areas until the later-formed leaves are almost green. That striping is a monogenic recessive has been recorded by many workers, Ramiah and Ramanujam [*loc. cit.*] and Morinaga, T. [*loc. cit.*]. This mutation has occurred in pure line cultures as well as in X-rayed material [Ramiah and Parthasarathy, *loc. cit.*].

In a cross between pure green and a striped plant, Mitra and Ganguli [*loc. cit.*] obtained 12 green : 3 striped : 1 albino and they explained it on the hypothesis that a gene **W** hypostatic to green **G** was responsible for the striped character. This striping may be different from the one Ramiah was dealing with. Pal and Ramanujam [1941] have described a peculiar green-and-white striping which was present on the leaf sheath and which persisted in the mature plant as well as on the grains. It was, however, a simple recessive to the normal. The gene controlling this character may be designated **vr**.

(2) *Green-and-yellow striped seedling.* This type is similar to the above but the green stripes in this case develop over a yellow instead of over a white background. The leaves turn green eight to ten days after germination and are then indistinguishable from the normal. Ramiah and Ramanujam [*loc. cit.*] obtained this mutation in a pure line but since the observation was made late, counts could not be taken in the segregating F_2 family. Of 20 progenies grown in F_3 one bred pure for the mutation, 18 were pure for green and one segregated for green and yellow striping character. The behaviour of the F_3 not conforming to any Mendelian segregation was not clear. That this was not due to any differential mortality of seeds was evident from the fact that 98 per cent of the total seed germinated. No apparent spikelet sterility was present either. No satisfactory explanation could at present be offered with the available data. That it is a recessive may be tentatively accepted.

(3) *Yellow-and-white striped seedlings.* This character is also confined to the seedling which starts with its first and second leaves (may be a third and fourth in some cases) marked by yellow stripes on white background gradually turning green through yellow. This mutation was isolated by Ramiah and Ramanujam [*loc. cit.*] as a double recessive in a cross between a green-and-white striped plant and a virescent yellow. This mutation may perhaps be brought under virescent types.

(4) *Zebra-marked seedlings.* The leaves show horizontal white bands which are marked in the seedling stage, and which persist for about a

month after transplanting and later disappear. Ramiah and Ramanujam [*loc. cit.*] recorded this mutation for the first time in rice from a pure line. This deficiency behaved as a recessive to the normal green. Later Ramiah and Parthasarathy [*loc. cit.*] obtained similar mutations in X-rayed material with yellow bands as well as white bands but the former was lethal and died early.

Each of these mutations behaved as a simple recessive to the normal green giving a 3 : 1 ratio. These may be designated **zy** and **zw**, **zw** is epistatic to **zy** and gives a 3 : 1 of **zw** to **zy.** Another segregating family in the X-rayed material gave 9 green : 3 white banded : 4 yellow banded lethal confirming the above hypothesis. Kadam (unpublished records) obtained two types of zebra-marked seedlings governed by complementary genes which have been designated by him as $\mathbf{z}_1$ and $\mathbf{z}_2$.

(5) *Blotched white.* In this X-ray mutation which was described by Ramiah and Parthasarathy [*loc. cit.*] there were spots on the leaf giving a pie-bald appearance. The character was found to be a simple recessive to normal.

B. Non-Mendelian inheritance

Certain chlorophyll deficient types have been shown to follow the non-Mendelian type of inheritance. The plasm including the plastids show the same kind of genetic continuity as the chromosomes and would, therefore, suggest that they are also efficient bearers of hereditary qualities. In certain chlorophyll deficient mutations, it has been shown that they arise as sectorial chimeras and the inheritance is through plastids and the pollen has no influence on the resulting progeny. Ramiah and Ramanujam [*loc. cit.*] have described three such cases (variegated plants) in rice.

(1) *Variegation*

(a) *Green and white variegation.* Some plants with this pattern were grown and the progeny from each tiller studied separately in one. It was found that the progenies of four plants although showing variegation yielded only green progenies. There were one or two albinos in one progeny which might have arisen as a plastid or gene mutation. A variegated plant from another family on selfing gave greens, albinos and a few variegateds but the ratio did not conform to any Mendelian expectation. In another family detailed observations were made on each sub-branch of the panicles of a few tillers in the variegated and green classes. All the green tillers gave green progeny and the variegateds gave mostly white or green progeny only. It was also observed that the seed on the ears of variegated plants giving rise to either albino or green seedling was not randomly distributed as would be expected if the inheritance was Mendelian, but was in patches. Certain heads gave only albinos and certain others only greens. This is in accord with the view that the character is transmitted not through the nucleus but through the plasm and plastids.

The direct relation, which is found between the appearance of maternal tissue and the kind of seedling it produces as in sorghum and maize, does not apply to this kind of variegation in rice. This discrepancy may be explained as due to difference in hereditary constitution between the sub-epidermal tissue. To see if this character is transmitted through the pollen, reciprocal crosses were made between variegated and green plants. Pollen collected from flowers in a region devoid of chlorophyll was used to fertilise normal green spikelets, conversely crosses were made using pollen from the normal plant to fertilise spikelets situated in the chlorophyll deficient areas of the ear. The results were :

Cross	F_1 progeny		
	Green	Variegated	Albino
(1) Variegated ♀ × Green ♂	13	..	3
(2) Green ♀ × Variegated ♂	10	..	..

It is seen from the above that pollen from variegated parts has no part in transmitting the character while the egg, if it has the normal plastids, transmits the character to the progeny. The fact that only three of the F_1 seeds in the first cross gave albinos is due to the fact that all the flowers were not borne on the chlorophyll deficient or transitional tissue. Morinaga [loc. cit.] obtained certain variegated types which gave a high percentage of albino seedlings every year. The seed folded in white lemma and palea produced only white seedlings while those in green lemma and palea developed into striped individuals. The seed folded in striped lemma and palea, produced both albino and striped individuals. When these variegated types are crossed with a normal green variety, the F_1 plants are either green or striped, simply resembling the material parent. The green F_1 produces only green offspring while the striped F_1 produces albinos and striped ones in irregular proportions.

(b) *Green-and-yellow variegation (yellow fading to white).* It was found that the behaviour of these plants on selfing was very similar to the green and white variegated described above except that in these, lethal yellows were obtained as segregates instead of white. Similar to the above mutation, different tillers gave rise exclusively to one type of seedlings. The male gametes did not transmit the variegation to the progeny.

(c) *Green-and-yellow variegation.* The third type of mutation was less frequent than the two mentioned already. The yellow lingered for a longer time and it appeared possible to rear them to maturity with proper precautions. It is reported by Hann [loc. cit.] that when they are not exposed to full sunlight it would seem possible to raise *xantha* plants to an older age. In other respects the green-and-yellow variegated mutation behaved similar to the above two mutations.

Kondo and others quoted by Matsura [1933] obtained a spontaneous green and white variegated plant, the variegation being present not only in leaves and panicles but also in unripe grains. These gave varying proportions of green, variegateds and albinos such as (1) 63 albino : 33 variegated : 4 green ; and (2) 95 green : 5 albino. When taken from a variegated part, white gave 92 per cent white and 8 per cent variegated, variegated gave 94 per cent green and 6 per cent variegated and green gave 92 per cent green ; 4 per cent albino and 4 per cent variegated. In crosses variegation was not transmitted through pollen. Variegated plants gave the same type of offspring whether selfed or pollinated with pollen from green. Hence the character is non-Mendelian in inheritance.

Imai [1928] has recorded two types of green and white variegations. When self-fertilised, one type gave almost exclusively green and albino progeny, conforming to ordinary non-Mendelian inheritance. The other type belonged to a special class and gave on selfing 30.7 per cent variegateds, 64.5 per cent albinos and 4.8 per cent greens. This condition, where the variegateds reappear in great numbers in the progeny has been explained as belonging to a special category in which the plastids are variable and mutate to green or white, the alteration of the plastids occurring quite out of control of genetic factors.

(2) *Albino*

Pal and Ramanujam [*loc. cit.*] have described a new type of variegation which when selfed gives rise to variegated plants and albinos in varying proportions but when crossed reciprocally with green plants gives rise to normal greens in the F_1 generation. Heterozygous green plants segregate into green and variegateds in the ratio of 3:1 and no albinos are present in the progenies. Thus while 'variegation' is a Mendelian recessive to green, 'albinism' is transmitted materially.

5. CHARACTERS OF THE PANICLE

The earhead in rice is borne at the end of each vegetative shoot and consists of a branched panicle with complete flowers or spikelets. Each of these branches in turn carries a number of spikelets, rarely in clusters but commonly in singles attached to a small rachilla. A large number of genetic variations in the panicle which affects its development has been recorded; these variations refer to size and thickness, arrangement of spikelets, variation in the size and colour of the glumes, lemma and palea, fertility of the spikelets, etc.

(1) *Panicle*

(a) *Aberrant types* Kondo *et al.* 1927 quoted by Matsura [1933] isolated a plant which had a slender and a large panicle with branches remaining erect even when fully mature. The grain was narrow, spindly, crooked with poor quality of rice. It behaved as a monogenic recessive to the normal. In the X-rayed material of rice, Ramiah and Parthasarathy [*loc. cit.*] isolated an abormal type, highly sterile with malformed, stiff panicle on which the spikelets were sparsely arranged and had reduced floral parts. This behaved as a simple recessive to the normal. Another X-ray mutation with malformed earhead containing rudimentary intervening spikelets was obtained by the same workers. The mutation gave a ratio of 69 malformed type to 36 normal which was not intelligible. A large number of mutations from X-rayed rice involving panicle malformations has been recorded by Ramiah and Parthasarathy and while the genetics of several of them have not been studied, of those that were studied, the inheritance appeared complicated.

(b) *Exsertion*. The portion of the peduncle from the junctura of the flag leaf to the lowermost internode of the rachis which is called exsertion varies a great deal in the different rice varieties. At one extreme we have varieties whose ears are carried far out with a long exsertion and at the other we have varieties like the *sathi* of the United Provinces whose earheads remain mostly enclosed within the sheath, 'the sheathed ear' type. This character, exsertion, to all appearance may seem un-important but withal it has an economic significance. Though panicles with very long exsertions are liable to break in high winds at the time of harvest, the very poorly exserted ones are generally found to suffer from various degrees of spikelet sterility which affect yield. Another observation made in Coimbatore in connection with *Piricularia* incidence is that a plant with a poor exsertion is more liable to attacks of the disease than one with a good exsertion.

'Exsertion' was studied quantitatively at the Paddy Breeding Station, Coimbatore [Ramiah, 1932] in a large population of an F_2 generation of a cross between a variety with poor exsertion and one with good exsertion. The distance between the junctura of the flag leaf and the lowermost node in the panicle was measured in each plant. Where the exsertion is poor, this node will be below the junctura and the measurement is prefixed by a minus sign. It was found that the frequencies when plotted gave a normal curve with the node roughly at the mean of the parental types with a high coefficient of variation in one cross (14 cm.). In another cross where the parents had almost similar exsertions there was transgressive variation in the F_2 generation, the range extending from 4 cm. to 22 cm. In a still another cross where the parents had − 7 cm. (partly enclosed) and + 6 cm. exsertions, the F_2 again gave a transgressive variation, the range extending from − 10 to + 13 cm. In the F_3 generation of the last mentioned cross none of the extreme types bred pure. Earlier studies made at Coimbatore by Parnell and others (unpublished records) had shown that in the F_2 of a cross between parents, one with 1 cm. exsertion and the other + 6 cm. exsertion, the exsertion of phenotypes ranged from − 11 to + 13 cm.

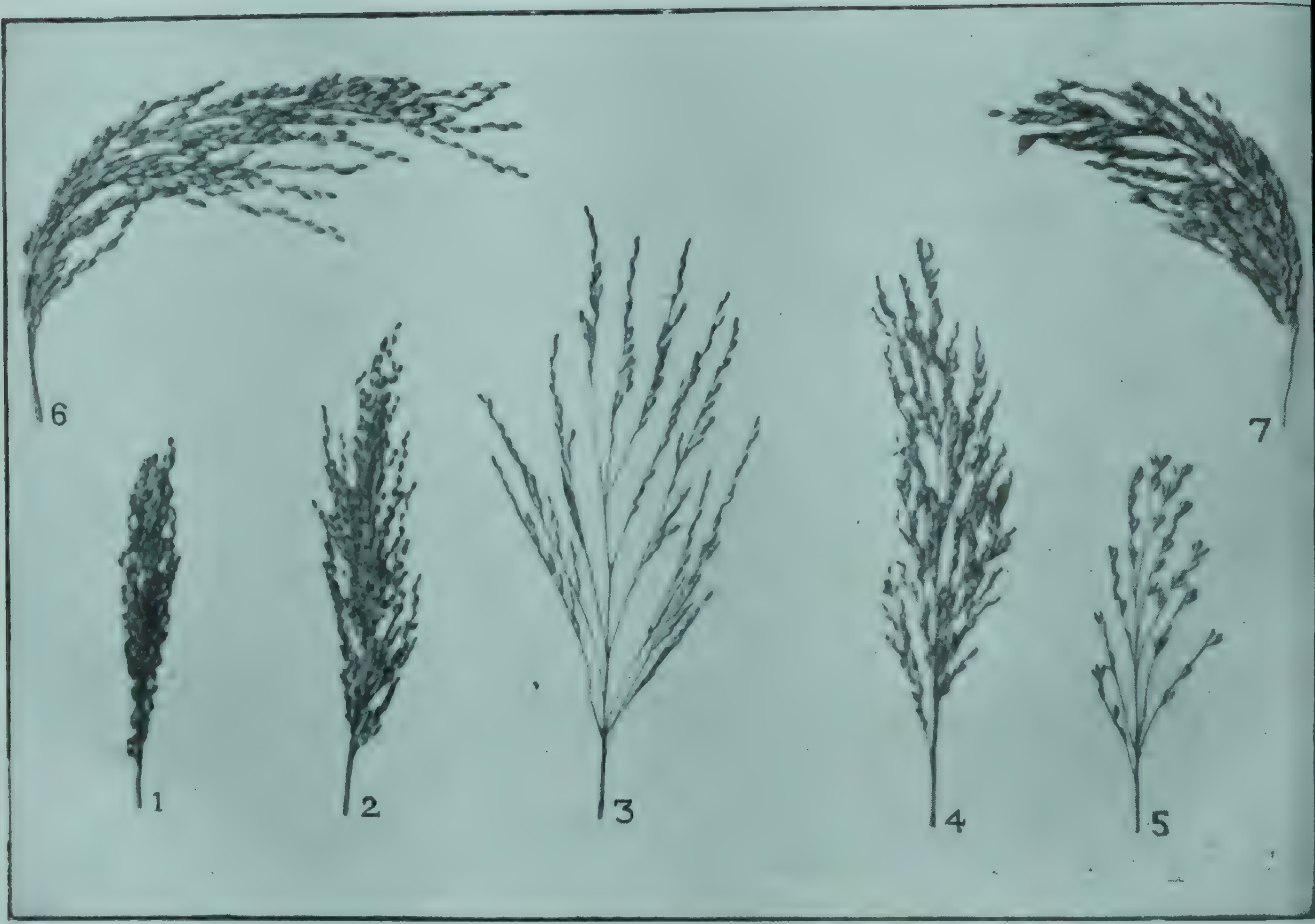
In the F_3 generation, 40 families were studied and it was found that almost all of them were still segregating ; the coefficient of correlation between the F_2 parent and F_3 progeny was also very small and not significant. Thus the inheritance of this character would appear to be controlled by a large number of genes.

Sethi *et al* [1937, a] working with crosses between the enclosed ear of *sathi* variety and normally exserted types found that 'exserted' ear was dominant and got a wide range of exsertions in the F_2 generation. They found that environment influenced the degree of enclosed or exserted condition. They classified qualitatively the degree of exsertion in the F_2 into four classes and obtained the following frequencies :

F_2 classes

Exserted	**Exserted and partly exserted**	**Tip exserted**	**Enclosed**	
Observed	**547**	**37**	**117**	**$\chi^2 = 2{\cdot}18$ P between 0·3 and 0·5**
Calculated 49 : 3 : 12 ..	**537**	**33**	**131**	

PLATE XVI



1. E. B. 304   2. T. 297.   3. T. 24.   4. T. 298.   5. E. B. 331.   6. E. B. 301.   7. E. B. 197.

Variation in density of panicle. (Coimbatore).

(After Ramiah and others 1931.)

There was some difficulty in classifying the group 'partly exserted' and 'exserted', and hence these were later combined into one class. The authors have explained the ratio on a three factor hypothesis, with a number of assumptions.

Forty F_2 plants were studied in the F_3 generation and many of the expected segregations were realised in the F_3 generation. There were still small differences between the individuals in the same phenotypic group and these they explained as possibly due to genes of minor importance. The hypothesis assumes a number of complex reactions of the genes and it would appear doubtful whether all that is necessary. Probably the results could be explained on the assumption of a major gene controlling exsertion and two modifiers.

It is certain that exserted condition must be dominant over enclosed condition. All the wild rices have a highly exserted panicle. Ramiah and Parthasarathy [*loc. cit.*] did actually obtain a mutation in X-rayed material with a reduced exsertion, almost minus, where the parent variety had a long exsertion.

(c) *Neck.* Jones [1933] has reported a cross in which one of the varieties had a wavy or sinuous neck or peduncle. This character sinuous was found to be dominant in the F_1 generation and in the F_2 a ratio of 15 : 1 of sinuous to straight neck was realised. So sinuous neck might be assumed to be caused by two dominant genes which may be designated $\mathbf{Ne}_1$ and $\mathbf{Ne}_2$. In the F_3 generation, however, in addition to the 3 : 1 and 15 : 1 ratios of sinuous to straight neck, the author obtained also ratios of 9 : 7 and 2 : 1. This was difficult to explain but the author believed that the character being a difficult one to diagnose, climatic factors might have distorted the ratios which were really a 3 : 1.

(d) *Panicle density.* By density of panicle is meant the number of grains per unit length and it must, therefore, depend upon the arrangement of the spikelets on the sub-branches, the number of branches, the length of rachilla of each spikelet, the size of grain, etc. The density of panicle varies greatly in different varieties of cultivated rice. The wild rices are characterised by a very low density and the ears are very open with sparsely arranged spikelets. Some of the cultivated rices possess loose and open earheads while others have a characteristic dense panicle resembling that of *bajra* (*Pennisetun typhoideum*), (Plate XVII). Although no quantitative measurements of density have been made, the character has been studied qualitatively by a number of workers who have classified the earheads occurring in segregating families into lax and dense groups.

In India, Bhide [1926] and Ramiah [1930] found the lax type i.e. where the spikelets are arranged sparsely to be a simple dominant over the dense type. The latter author found that in the F_2 classification of lax types, there were variations from the typically lax to a slightly dense arrangement but the F_3 behaviour of the types justified their being put into a single class. Grant [1935] confirmed the simple recessive nature of dense panicle in his studies with Burma rices. The typical cylindrical earhead of one of the Burma varieties called *'Cigar shaped'*, described under dwarfs, has also been found to be recessive to the lax nature [Parnell *et. al.*

1922]. The gene governing the recessive dense character may be designated lx_1. In a cross between wild rice with the typical lax panicle and a cultivated variety with a dense panicle, Mitra and Ganguli [1932] obtained in the F_2 a ratio of 9 lax : 7 dense panicles. In this case the recessive dense type is governing by two complementary genes.

In Japan, Nagai [1926] obtained evidence of the dominant nature of the normal lax over dense panicle but Kato [quoted by Matsura 1933] in his material obtained continuous grades of compactness in the F_2 generation, the F_1 being intermediate in density. Takezaki [1932] found that when two varieties with almost similar density were crossed the F_2 showed four types based upon the number of grains per cm. length, viz., normal or dense type with 4.81 and three other types with 2.19, 1.43 and 0.18 number of grains per cm. length respectively. He explained them on two pairs of allelomorphic genes. The dense was K_a K_b, type II was K k_b type III k_b k_a and type IV k_a k_b. In this case denseness appears to be dominant.

Bhide [*loc. cit.*] found some degree of association between panicle density on one hand with small size of grain and sterility at the tip of panicles on the other. From an examination of the several pure lines grown at Coimbatore, Ramiah [*loc. cit.*] found that the dense type of panicle was invariably associated with small or medium sized spikelets and never with large ones. Since most of the wild varieties of rice have a lax panicle it may be reasonable to assume that the dense type must have arisen as a mutation and because of its usefulness preserved by man through cultivation.

(e) *Clustering of spikelets.* Somewhat different from the dense arrangement, is the *clustering* habit of the spikelets which is met with only in a few rare varieties of rice. Although the spikelets of the rice panicle usually remain solitary, it is found that in one or two varieties. they are clustered on the secondary branches, two to seven spikelets occurring close together. The branches of the panicle have consequently a slightly interrupted appearance. Probably to compensate for this clustering character, the length of the panicle is reduced. Crosses were made between the 'cluster' variety and the premier strain Geb. 24 at the Paddy Breeding Station, Coimbatore [Ramiah, 1930]. The F_1 was more like Geb. 24, except that at the tips of the main and secondary branches of the panicle the spikelets appeared mostly in twos. The F_2 gave three groups of plants in a 1 : 2 : 1 ratio of normal : F_1 : cluster group. The extracted cluster type from the hybrid progenies was very similar to the parent cluster in panicle length, and it was, therefore, found impossible to combine clustering of spikelets with a greater length of panicle. Sethi [1936] also obtained similar results from a natural cross. The clustering and non-clustering may, therefore, be taken to form a simple pair of allelomorphs, 'clustering' being partially dominant. The gene may be designated **Cl**. the normal being cl.

A cross between a variety with a 'dense' type of panicle and the 'cluster' type was studied by Ramiah *et al.* [1931]. As expected the F_1 was lax and 'intermediate for cluster' and six groups of phenotypes with regard to density and clustering were obtained in the F_2 generation and the frequencies are given in Table VI.

TABLE VI

F_2 segregation in cluster x dense panicle cross

Family No.	Typical cluster, lax panicle	Inter-mediate cluster lax panicle	No cluster lax panicle	Cluster and dense panicle	Inter-mediate cluster and dense panicle	No cluster but dense panicle
	*SSCC or SsCC	SSCc or SsCc	SScc or Sscc	ssCC	ssCC	sscc
6202	147	321	148	50	108	70
6203	167	328	135	44	93	70
6204	123	241	138	40	89	49
6205	138	266	116	35	68	56
6206	163	324	135	29	61	47
6207	142	272	158	22	94	80
6208	174	360	200	51	106	93
6209	119	323	153	27	87	55
Total ..	1,173	2,435	1,183	298	706	520
Cal., 3 : 6 : 3 : 1 : 2 : 1 ..	1,185	2,370	1,185	395	790	395

* C ' cluster grain ' factor ; S ' lax panicle ' factor.

It was found that when the two characters, denseness of spikelets and clustering occurred together, the classification into sub-groups, was extremely difficult and though the χ^2, estimated individually for the families, does not show good fit, the ratios for the two characters taken separately agree fairly with expectation. It may therefore be stated that these two characters segregate independently. Kadam (unpublished records) had crossed different cluster varieties with normal and his results appeared to indicate that the normal type was recessive, the F_2 s giving 63 of cluster of various degrees to 1 of normal suggesting 3 genes for the character.

(f) *Panicle length.* Obviously the length of panicle in rice must be a very variable character and it has a definite relationship to yield. In the varietal collection maintained at Coimbatore the average length of the ear measured from the bottom-most node to the tip of the panicle is found to vary from 13 to 42 cm. If greater length of panicle could be combined with other characters it would prove a valuable improvement. But Ramiah [1930] showed that panicle length and panicle number do not go together. Incidentally the inheritance of length of panicle was studied in this cross and the results are set out in Table VII.

TABLE VII

Frequencies of length of panicle in an F_2 of a cross.

(Mean length of panicle in cm.)

Particulars	20·5	22·5	24·5	26·5	28·5	30·5	32·5	34·5	36·5	38·5	40·5	42·5	Total	Mean
Geb. 24 parent..	..	..	..	1	25	1	..	2	..	..	..	..	29	28·7 ±0·14
Java parent ..	..	..	..	..	..	..	..	3	3	13	4	..	23	38·1 ±0·18
F_1 ..	..	..	..	..	..	2	3	2	..	..	..	..	7	32·5
F_2 ..	3	4	17	76	224	372	280	155	64	14	2	1	1,212	31·1 ±0·044

The wide range of panicle lengths and a large coefficient of variation in F_2 should show that the character is governed by a number of genes. Several other workers in India and abroad, Bhide [1926], Grant [1935] and Kato [quoted by Matsura, 1933] have recorded that this character was governed by multiple genes.

(g) *Thickness of peduncle.* The thickness of the peduncle is subject to a great deal of variation in rice varieties. It is reasonable to expect a bunched heavy ear to be supported by a thicker peduncle and this has been found to be the case by studies in a number of varieties by Joshi and Gadkari [1923]. No inheritance studies are, however, available with regard to this character.

(2) *Glumes*

(a) *Size.* In normal cultivated rice the glumes of the spikelets, are two. small and inconspicuous structures situated at the base of the spikelet, about 1/4th to 1/5th of the size of the lemma. In a few varieties these glumes are as long as the lemma and palea and sometimes even longer giving them the characteristic winged appearance. and they are hence called *winged spikelets.* The length of the glume has been used by some workers as a basis for classifying rice into subspecies as *O. sativa* var. *longiglumis* or *O. sativa* var. *grandiglumis.* In crosses between normal glumes and long glumes (T. 290). Parnell *et al.* [1917] obtained a clear cut ratio of 3 : 1 of normal glumed to long glumed plants. the small glume being completely dominant over the long glume. In another cross between a different long glumed variety (E.B. 141), where the glumes were even longer than the lemma and palea, Ramiah *et al.* [1931] obtained an intermediate type of glumes in F_1 and a ratio of 1 : 2 : 1 of normal : inter : long glume in the F_2 generation where the interglumes were somewhat shorter than the lemma and palea. It is evident from the above that the character of long glumes in E.B. 141 is genetically different from that observed in T. 290 by Parnell and others. There was no association of long glumes with other characters such as colour of lemma, size of grain etc. Van der Stok [1908] stated that the normal type was a simple dominant. Kadam *et al.* [1941] obtained a long glume mutation in a pure strain which bred pure in later generations.

Chao [1928, a] has recorded results giving a 15 : 1 ratio between normal glumes and long glumes. It is probable that the genetic factors controlling the size of glumes are different in different varieties. The dominant duplicate genes for the normal glume may be designated $\mathbf{G_1}$ and $\mathbf{G_2}$, the long glumed condition being governed by g_1 and g_2, the gene concerned in the 3 : 1 ratio obtained by Parnell may be either of these. The partially dominant gene observed by Ramiah *et al.* [*loc. cit.*] may be either different from these two or the same, the difference in behaviour being due to the different backgrounds on which they act.

(b) *Colour.* The pigment characters of the glumes are not so complicated as those of lemma and palea. There are only three colours so far identified. white (straw). brown and purple of different shades. Some workers report also of a reddish colour in the glumes but it is in all probability only a shade of purple. The brown sometimes called 'tawny' by some workers occurs in association with the rich ripening brown colour of lemma and palea. The purple generally occurs where the colour in the apicalus of lemma and palea spreads a little lower down.

(i) *Purple.* Hector [1922] crossing two green glumed plants obtained an F_1 plant with purple glumes and 9 purple to 7 green glumes in F_2. In another cross a simple ratio of 3 purple to 1 green glumes was realised. Mitra *et al.* [1928], Jones [1930, a] and Ramiah [1932] obtained similar results. The genes may be designated **G**$_{pa}$ and **G**$_{pb}$.

(ii) *Red.* Jones [1933] has reported that the colour in the glumes in some of his varieties was red and a ratio of 9 red to 7 green glumes was obtained in a cross between two varieties. If the description 'red' is taken to correspond to some form of purple due to the presence of anthocyanin, these results might be taken as similar to those of Hector. If, however, the red colour is different, the genes may also be different.

(iii) *Tawny.* Chao [*loc. cit.*] has described a particular variety in which the apiculus and the glumes were green at first but changed through several shades of orange yellow to tawny on the ripening of grains. This character was found to be a monogenic dominant over colourless or white glume. This gene has been designated **G-t**, same as that of ripening tawny of lemma and palea.

There are some varieties with tawny glumes in the pure line collections of the several workers in India but the inheritance of this particular character does not seem to have been studied by them.

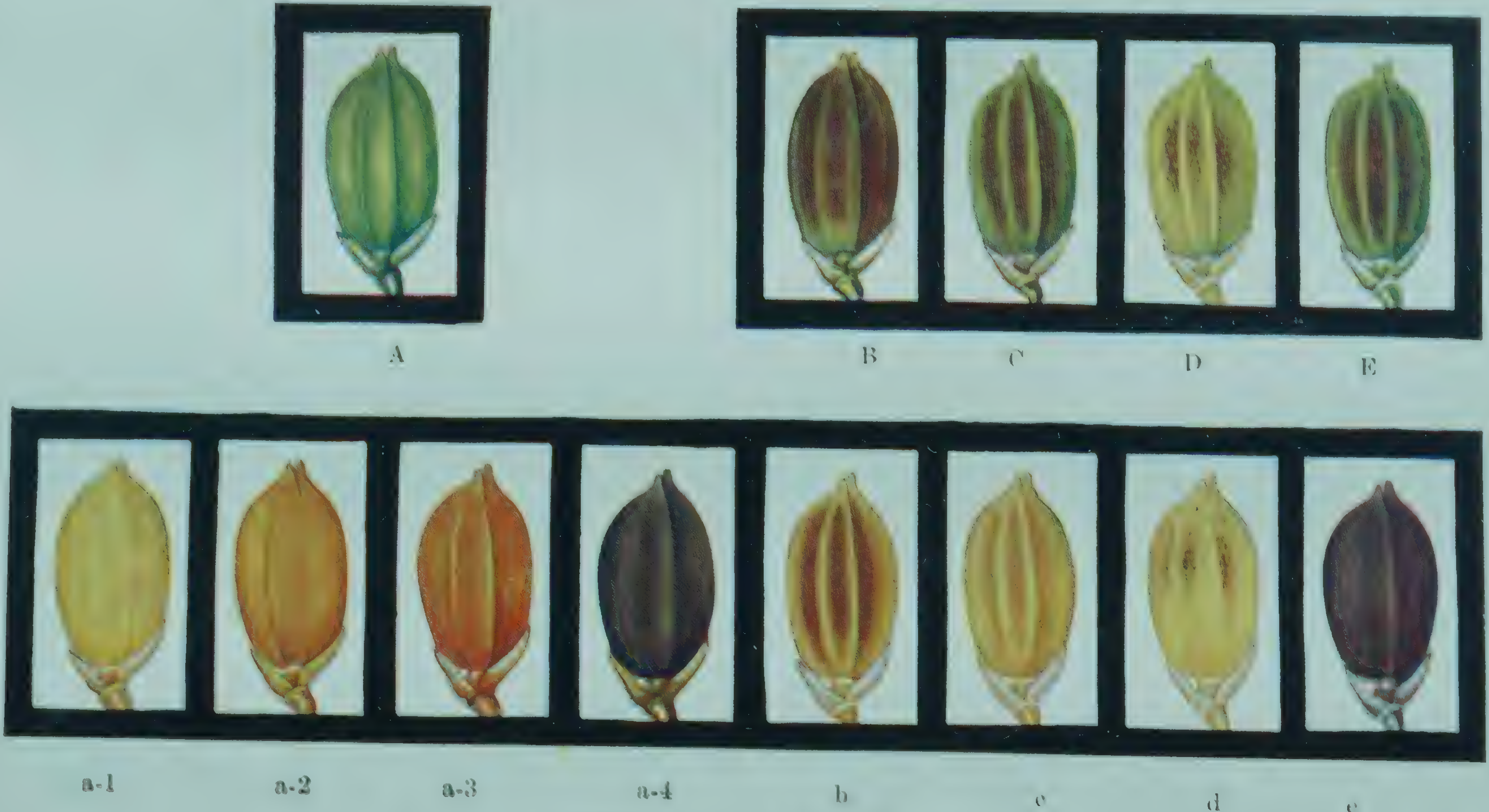
(3) *Lemma and palea*

(a) *Abnormalities.* Ramiah and Parthasarathy [1938] obtained in X-rayed material a number of mutants, abnormal in the size and shape of lemma, amongst which may be mentioned (1) glume deformed in some cases, the lemma or palea being completely absent; (2) beaked and slender grained (3) ill formed, the intervening spikelets being rudimentary. A large number of sterile mutants with deformed spikelets also occurred.

(b) *Colour.* Probably no single morphological structure of the rice plant shows such a great diversity in pigmentation as the lemma and palea. In the nature and degree of colouration there is considerable variation. The colour when present is exactly the same in both lemma and palea and hence if lemma alone is referred to in the following descriptions it includes palea also. When dealing with colour in lemma, one has to bear in mind that often the colour which is seen in the flowering stage changes into quite a different one at the ripening stage. Though the colour in the lemma has not been found to be of any special economic value, it has been used previously in the classification of rices. The colour description of lemma and palea that may be followed by Indian workers has been standardised by Hutchinson and Ramiah [1938]. The most common colour of lemma is light green when young, ripening into pale straw. The straw colour may often be found variable. In some rices the straw colour appears brighter than in others, and the former is always preferred by trade. The dull looking straw colour in some rices may be due to the red colour of the pericarp inside. The more common amongst the other groups of colour is what may be termed the gold colouring which may vary from orange-yellow to reddish-brown at flowering, becoming darker and duller on ripening. The pattern of this colour may also vary in different types.

Plate XVIII a

LEMMA AND PALEA COLOURS


A
B
C
D
E
a-1
a-2
a-3
a-4
b
c
d
e

(HUTCHINSON & RAMIAH, 1938.)

Frequently the colours are confined to the furrows between the nerves, the nerves themselves being paler. When anthocyanin pigment is present, it may be confined to the apiculus or it may be spread all over, the intensity again varying in different types from light red to dark purple (almost black). Altogether 19 types of colour are represented in the plate attached (Plate XVIII a-c) and it should be possible to match most of the known colours of lemma against these. It may happen that types may occur that do not strictly conform to these standards and they may have to be described separately.

Until recently the rice workers have been describing lemma colours in different ways in their publications dealing with inheritance studies, and this has made the question of bringing all the results under one general scheme extremely difficult. It is believed that the several colours in lemma and palea may represent several multiple allelomophic series but with the present available knowledge on the inheritance of these characters, it is not possible to establish the relationship between all the different colours. The colour present in lemma and palea may conveniently be grouped as follows :

I. *Colour in the young stage*

(a) *Green* ripening to straw, referred to variously as fawn, white and yellowish white ; this is the most common colour.

(b) *Very light yellowish green,* which ripens into gold.

(c) *Dark blackish brown* specially in furrows ; ripening into rusty brown in furrows.

(d) *Gold*—becomes darker as it ripens (referred to as dark gold, orange and light brown in literature).

(e) *Purple*—purple tips, purple spread lemma and full purple (fading slightly on ripening).

(f) *The piebald and mottled patterns.*

II. *Colours on ripening*

(a) Ripening into white, straw or fawn.

(b) Ripening black—all distinguishing colours when young may ripen into this colour.

(c) Ripening tawny—Green when young ripens into this colour.

Since all anthocyanin colour factors are known to behave independently of the other colour factors both from studies in Coimbatore and Bengal, these are dealt with separately.

Gold colouring of lemma and palea in relation to the other colours such as straw, piebald and dark furrows was studied by Parnell *et. al.* [1929] rather exhaustively. In their investigations four genes were identified with certainty. They were able to explain most of their results on the basis of these four genes and occasionally there was a suggestion of fifth gene also.

To be sure of the nomenclature used by different workers in India to denote particular colours, actual samples of grain were obtained from them for comparison before bringing them into one general classification.

Wherever the available data are definite to postulate multiple allelomorphism of genes it has been done.

Gene symbol	Gene action
m	Mottling as differentiated from self colouring.
.. ..	Piebald distribution of gold.
H^g	Green.
f	Gold or orange.

The above four form a multiple allelomorphic series.

I^h	A gene inhibiting the colour which is governed by each of the above genes. In its absence the colours change into corresponding gold or orange colours.
H^t ..	Controls distribution of the gold or orange colour over lemma and palea producing the tip and base and the tip gold forms.
H^p	Localisation gene for purple in the lemma and palea.
H^{ep_1}	Controls the extension of the purple colour in purple spread.
H_{ep_2}	Controls the extension of purple colour in full purple.

The constitution of the several colours in the lemma is as follows :

$H^{pb}H^{pb}IhIh$	Piebald distribution of blackish spots when green ripening into straw (the dots may disappear or persist). The same gene brings on the piebald pattern on gold.
H^g H^g $IhIh$	Green ripening into straw or lemon yellow.
H H $IhIh$	Blackish dirty in furrows, ripening brown.
H^f H^f $ihih$	Gold in the young stage ripening dark gold or reddish brown.
H^g H^g $ihih$ ..	Goldish in young stage (ripening later to light gold or orange yellow).
H^tH^t $iihiHtHt$ ..	Tip and base gold, patchy gold, etc.

The actual examination of the available genetical data is dealt with below :

(I) Colour in the young stage

(a) *Green* *(*straw A—a-1*) H^g *Ih x Dark furrows* (*ripening brown furrows B-b*) H^f *Ih*.—Many workers have investigated this cross. The F was green which ripened into straw. In the F_2 generation. a ratio of 3 : 1 of green to dark furrows was recorded by them [Parnell *et. al.* 1917]. Hector [1922], Ramiah [1935]. Mitra and Ganguli [1937]. Dav [1937] and Majid [1939]. H^g is dominant to H^f

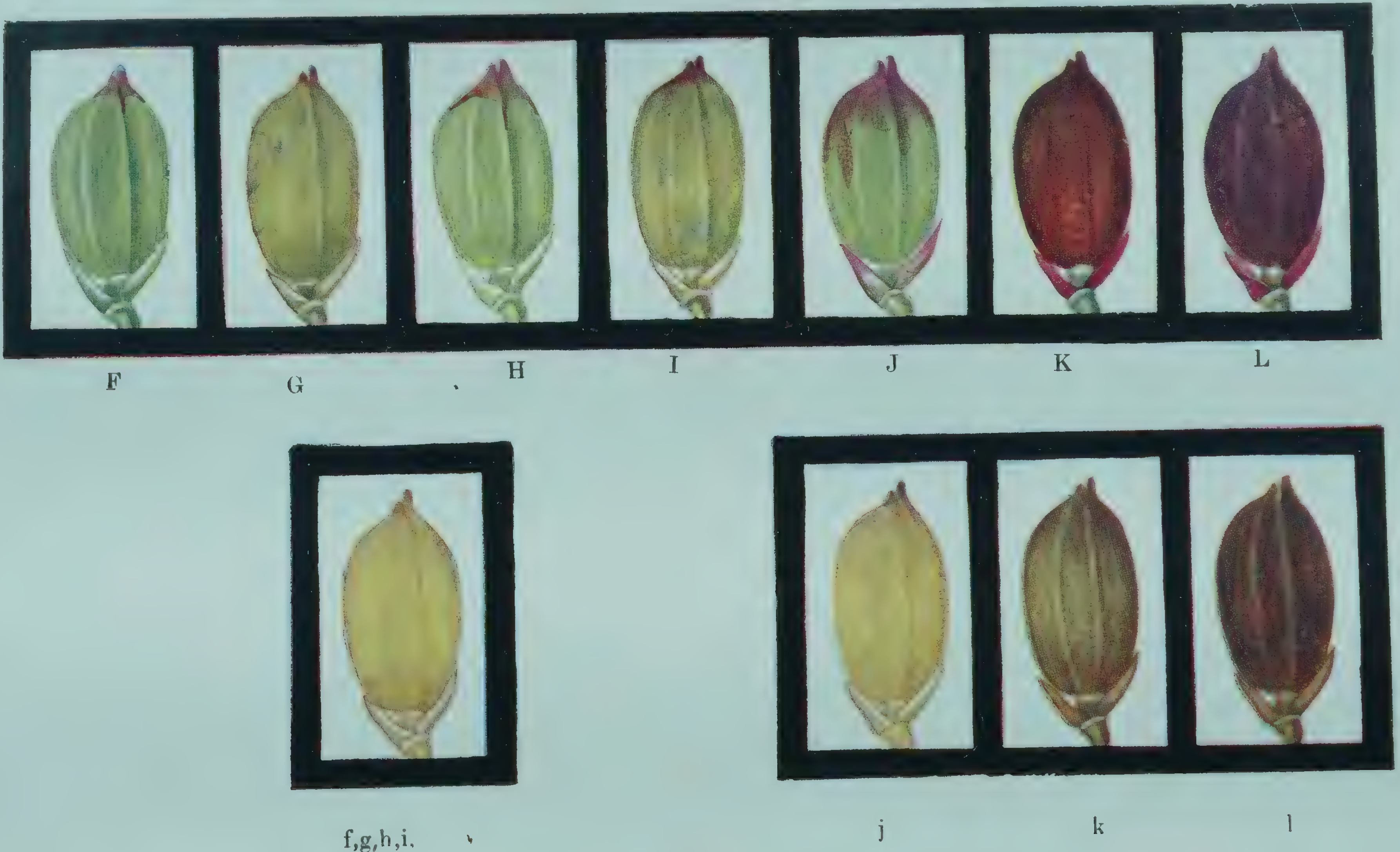
Ratios different from the simple 3 : 1 have been recorded by a few workers. Majid [*loc. cit.*] in one cross obtained in the F_2 generation a 13 : 3 ratio of straw to dark furrows indicating that an inhibitory gene

---

*The corresponding ripening colour is given in brackets and letters indicate reference to lemma colours in plates.

Plate XVIII b

LEMMA AND PALEA COLOURS


F
G
H
I
J
K
L
f,g,h,i.
j
k
l

was operating. Jones [1933] crossing two varieties which had yellowish brown furrows and straw furrows respectively had obtained a ratio which was just the reverse of what Majid got. F_3 analysis was, however, not done but it was suggested that the brownish yellow colour in furrows of lemma and palea appeared to be due to two genes.

(b) *Green (straw A-a-1)* H^g *Ih* × *Greenish (ripening gold A-a-2)* H_g *ih.* —Parnell *et al.* [1917] and Sethi [1938] obtained a 3 : 1 of green to ripening gold. The 3 : 1 ratio of white to dusty red, Thompstone [1915] and 3 : 1 of yellow to light brown, Mitra *et. al.* [1928] refer only to the same segregation. Alam [1936] realised a 13 : 3 ratio of straw to golden yellow but no F_3 studies were made to confirm it and it is possible it was only a 3 : 1 ratio. Here also the same character is concerned.

(c) *Dark furrows (brown furrows B and C)* H^f *Ih* × *Gold (Dark gold M)* H^f *ih.* In a number of natural crosses studied by Parnell *et al.* [1922], a monohybrid ratio of 3 : 1 of dark furrows to golds was obtained. Hector [*loc. cit.*] realised a ratio 3 dark furrows (which he called yellow brown) to 1 gold (brick red). The segregations were all for the single pair of genes Ih and Ih. Majid [*loc. cit.*] has reported a cross between gold and dark furrows in which the F_2 is recorded to be dark furrows and in the F_2 besides the two parental groups two other colours—straw and dark gold—were also obtained. No further analysis has been given by the authors. The gold of the author may be the ripening gold which is H^g *ih* and when it is crossed with ***H*** ^{f} *Ih* (Dark furrows) the F_2 should segregate into :

9 H^gIh	:	3 H^gIh	:	3 H^fih	:	1 H^fih
(straw)		(light gold)		(furrows)		(dark gold)

The two middle classes correspond to the parents and the extreme classes, straw and dark gold, would be the two new combinations, same as (d) below.

(d) *Green (straw A-a-1)* H^g *Ih* × *Gold (dark gold M)*H^f *ih.* Mitra and Ganguli [1937] crossing a green with gold (which they called brown) got a green (straw) in F_1 and in the F_2 they obtained a ratio of 9 green : 3 black green : 3 light brown : 1 brown. Narasingarao (unpublished records) found that in two crosses between a green and gold of different intensities, the F_2 gave 9 green : 3 black furrows : 3 patchy gold : 1 gold. Mitra *et al.* [1928] crossing a straw and dark gold (which they called respectively yellow and deep brown) obtained a segregation of 9 green (straw): 6 inter : 1 dark gold. All the above results may be explained on the factor hypothesis detailed before. In the standard terminology as proposed by Hutchinson and Ramiah, black corresponds to dark furrows, light brown is light gold and brown is gold, the same as in the original cross. The segregation will be the same as described under (c) above. Hector [*loc. cit.*] crossing a green glume, ripening straw (which he called yellow) and a dark gold type (red in his terminology) realised a ratio of 9 straw (yellows) : 6 inter (yellow): 1 gold (red). Thus F_2 segregation may be taken as resulting from heterozygotes of the constitution H^g H^f *Ihih* which would segregate in the ratio as shown above.

(e) *Piebald pattern.* In some natural crosses, Parnell *et al.* [1917] obtained segregations which approximated to a ratio of 9 piebald furrows (D) : 3 dark furrows (B) : 3 piebald gold (P) : 1 dark gold (M). This must be the result of segregation of a hybrid plant of the constitution $H^{pb} H^{f}$ *Ihih* which should give :

$$9\ H^{pb}\ Ih : 3\ H^{f}\ Ih : 3\ H^{pb}\ ih : 1\ H^{f}\ ih$$

(Piebald furrows) (dark furrows) (piebald gold) (dark gold)

where H^{p} is dominant to H^{f} . The same results follow from two crosses between green × piebald gold lemma (H^{g} *Ih* × H^{pb} *ih*). The F_1 was piebald, ripening straw and the F_2 ratios are given below (Table VIII).

TABLE VIII

	Piebald dark furrows	Dark furrows	Piebald gold	Gold	Total	
Observed Cross I	256	108	89	31	484	$x^2=6 \cdot 1$
Cross II	226	83	69	34	412	P is greater than 0·05
Total ..	482	191	158	65	896	
Calculated 9 : 3 : 3 : 1 ..	504	168	168	56	896	

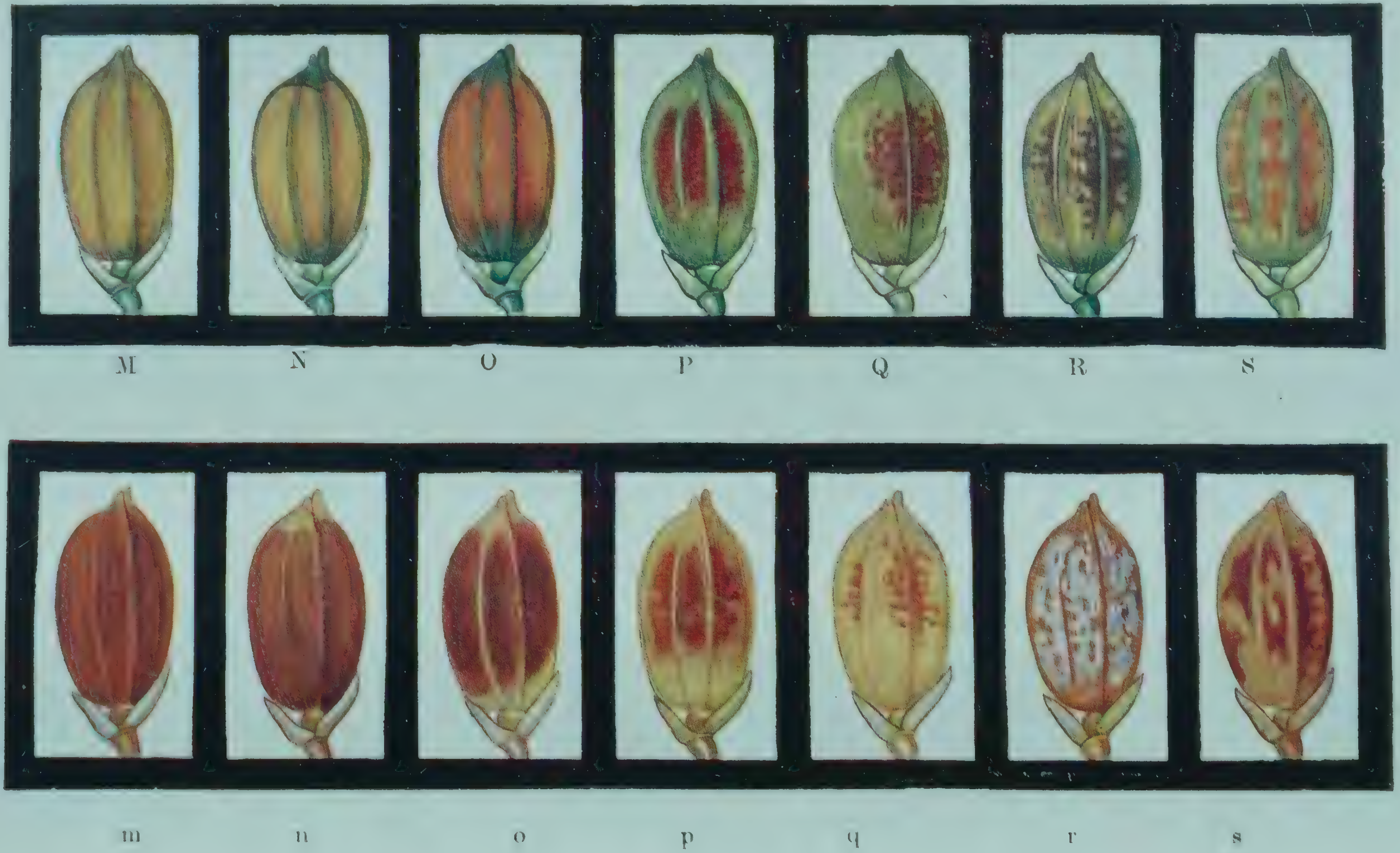
In certain other crosses there was only segregation between piebald furrows (ripening straw) and green (ripening straw) giving a simple 3 : 1 ratio. This should result from the segregation of a plant of the constitution $H^{pb}\ H^{g}$ where H^{pb} is dominant to H^{g} . Thus the presence of another gene allelomorphic to the above higher up in the series is demonstrated.

(f) *Mottling* × *Self colouring.* Parnell *et al.* [1928] found on several occasions that certain families derived from a natural cross segregating for some type of dark furrow colouring, showed a number of plants with mottled grain. (Plate XVIIIc, R. & S.). The mottling was not seen until the grains were practically ripe ; irregular light coloured areas would then appear scattered over the grain giving it a distinct moth-eaten appearance. The mottling is a stable character and breeds true to the type. Ramiah *et al.* [1931] studied crosses between mottled and dirty furrows. The F_1 was found to be mottled though the extent of mottling was less than in the parent. The F_2 segregated into a ratio of 1 : 2 : 1 of dirty : mottled like F_1 : typically mottled, with a very good fit ; the studies continued in the F_3 generation confirmed the F_2 results showing that mottling was incompletely dominant, the heterozygote giving a less intense type of mottling than the parent. In another cross between piebald lemma (H^{pb}) and a lemma with mottled dirty, the F_1 did not show the mottling clearly but in the F_2 there occurred 265 plants with mottling and 94 with no mottling which was evidently a 3 : 1 ratio. There was some variation in the piebald non-mottled class. But the dominant nature of mottling over piebald pattern was clearly brought out. Thus the gene governing mottling may be designated as H^{m} which is dominant to H^{pb} and H^{f} .

(g) *Green* (*straw A-a-1*) × *Green* (*Tawny A-a-3*). The cross was studied by Ramiah [1936] The F_1 was dark purple and in the F_2 a ratio of 9 purple : 7 non-purple was realised. Taking the basic genes for colour A and C and a localisation gene H_p for purple lemma, each of the parents have two genes of which one gene is common. Thus the tawny is shown to contain one of the basic anthocyanin colour genes.

Plate XVIII C

LEMMA AND PALEA COLOURS


M
N
O
P
Q
R
S
m
n
o
p
q
r
s

(h) *Purple.* The purple colour in the lemma and palea varies a great deal. The colour in the apiculus is possibly due to a separate localisation gene different from that concerned with the body colour of lemma. Though the occurrence of a type with coloured body of the lemma and green apiculus has not been reported, such a type would be difficult to distinguish in the field. Considering the distribution of purple in the lemma proper, we may have the colour extending a little lower down the apex when it may be termed ‘ tip and end ’.

(i) The purple colour may spread still lower when it is classed as purple spread ’.

(j) There are gradations in above two groups, and it is sometimes difficult to distinguish between them in segregating families and the extreme plant types in the two groups may merge into each other. It is therefore desirable to keep only one class in this and designate it as ‘purple spread’. We have finally the entire lemma and palea coloured purple with different intensities; at its maximum intensity the purple will appear as almost black which on ripening gives a smoky blackish brown, sometimes not very easily distinguishable from the ripening black character. It has been shown that the purple in the lemma is caused by a localisation gene $\mathbf{H}_p$. The purple spread and full purple are probably governed by extension genes Hep_1 and Hep_2 respectively. It may be pointed out that in many cases of inheritance studies the intensity or the localisation of purple in lemma has not been stated.

(i) *Green × green.* Parnell *et al.* [1917], Hector [*loc. cit.*] Kato [quoted by Matsura 1931], Mitra *et al.* [*loc. cit.*], Jones [1931] and several other workers obtained on crossing two varieties with green lemma an F_1 with purple lemma, which segregated into 9 coloured lemma : 7 green lemma in the F_1. Thus each of the parents must have had either two of the three genes A, C and H_p with one of them in common. Studies on F_3 progenies confirm this hypothesis in most cases.

A slightly modified ratio was once obtained when two green lemmas were crossed at the Paddy Breeding Station, Coimbatore, (unpublished records). The F_1 was some grade of purple spread and in the F_2 the following ratio was obtained : 9 purple spread : 3 green glume with purple tip : 4 green. The ratio can be explained by supposing that an additional gene Hep_1 acting in conjunction with the gene for tip colour gives the purple spread and the absence of either results in green.

(ii) *Full purple* (*K-L*) × *green* (*a*-1). Parnell *et al.* [1917] Mitra *et al.* [1928], Jones [1930, a] obtained a simple 3:1 ratio of full purple : green indicating that the parents differed only in the localisation gene. In crosses with other parents, full purple of various grades, purple spread, green with purple tip and pure green were obtained. The extreme classes of the lower grade in full purple and the purple spread group were not easily distinguishable and so no definite ratios of the above phenotypes could be made out. But when the purple and purple spreads were combined the ratio approximated to a 9:3:4 which is the same as the one already referred to.

(iii) *Full purple of lemma* (*K-L*) × *green lemma light purple tip* (*F*). The cross was studied at the Paddy Breeding Station, Coimbatore, by

Parnell and others (unpublished records). The F_1 had purple tip with purple spread colour and in the F_2 the following segregation was obtained :

	Full purple	Purple tip	Light purple	Total	
Observed	1,967	715	952	3,634	$\chi^2=6\cdot3$
Calculated 9 : 3 : 4	2,042	681	911	3,634	P is just 0·05

Yamaguti [1921] crossing a deep purple (violet black) and a green glume ripening yellowish white, realised in F_2 the following five frequency groups ; 27 purple entirely (BRS) : 9 purple at the two ends (BS) : 9 blackish red (RS) : 3 brownish tawny (S) : 16 yellowish white (combinations without S). The results were explained on a three factor hypothesis ; factor B standing for purple, R for entirely red and S expressing piebald, restricting the colour to two ends ; B and R are not able to manifest themselves in the absence of S. Nagai [1921] studied a cross between purple streaked and brown. The F_1 was brown with purple self colour and the F_2 gave 9 self purple : 3 purple and yellow : 3 brown : 1 yellow. The ratio was explained by supposing two factors, **P** a gene for purple pigment. **B** a gene for brown ground colour; it appears and either B has a simultaneous self action over purple, or another gene closely linked with it brings about the self colour. It is not found possible to bring the above two segregations under the factorial hypothesis adopted here, the main difficulty being that the descriptions of colour mentioned by the authors cannot be definitely identified.

(g) *Purple* H_p *IH—(K)* × *Ripening gold* H^g *ih* (*A-a-2*). In a cross between purple lemma which fades slightly on ripening and a gold lemma (green when young) the F_1 was a shade of purple with patchy gold the purple being lighter than in the parent (unpublished records of Coimbatore). The F_2 segregation was, as shown below ; there was some difficulty in distinguishing the different shades of purple and hence they were grouped under one class as purple.

F_2 frequencies of purple × ripening gold

	Purple	Purple patchy gold	Green straw	Gold	Total	
Observed ..	281	116	125	43	565	$\chi^2=10\cdot5$
Calculated 9 : 3 : 3 : 1	318	106	106	35	565	P between ·12 and ·01.

Twenty two F_2 plants were studied in the F_3 generation, and their behaviour entirely confirmed the dehybrid ratio in spite of the fact the fit was bad in F_2.

(II) Ripening colours of lemma and palea

The ripening characters, as has already been referred to, act independent of the colours at the young stage; different colours of the young stage may ripen to the same colour at maturity. Conversely the same young lemma colour may have different colours after ripening. A green lemma may ripen to shades of gold, black, brown or tawny or even purple. Hence the ripening colours are treated separately though they have not been studied to the same extent as the young lemma colours.

(a) *Ripening black* (*green A-a-*4)* × *Ripening straw* (*green A-a-*1). Parnell *et al.* [1922] working with natural crosses, obtained both 9 : 7 and a 3 : 1 ratio of ripening black to ripening straw in segregating families though the actual ratios did not show a good fit. A cross between a cultivated rice and a wild rice with ripening black character over green when young, studied at Berhampore gave a 9 : 7 ratio of ripening black to straw in the F_2 generation. Chao [1928, a] also obtained 9 : 7 of ripening black to yellow brown. Thus two complementary genes $H\text{-}b_a$ and $H\text{-}b_b$ may be assumed to be present controlling the ripening black character. The simple 3 : 1 ratio of black to straw can happen when either of the parents lack one of these genes.

(b) *Ripening black* (*dark furrows E-e*) × *Ripening straw* (*green A-a-*1). Mitra and Ganguli [1937] and Nandi and Ganguli [1940] have recorded a segregation of 36 black : 21 yellow : 7 blackish brown in F_2. The authors have explained it on a three-factor basis. The above ratio can however be explained on the basis of genes already suggested without assuming complicated reactions proposed by them and keeping the ripening and colours in the young stage separate. The yellow of the segregation is straw ($H^g\ Ih$) and blackish colour is dark furrows ($H^f\ Ih$); the young stage lemma colour should segregate into 3 H : 1 H^f or 3 yellow (straw) : 1 blackish green (dark furrows). The ratio for the ripening black to ripening straw is 9 : 7. When both the above segregations occur together one should get 36 ripening black, 21 ripening straw and 7 ripening dark furrows which is exactly what the authors have obtained. Thus the ripening black genes segregate independent of the lemma colours in the young stage.

Jobithraj [1936] studying a cross between straw and ripening black got a ratio of 9 ripening black (green) : 3 ripening straw (green) : 3 ripening black (dark furrows) : 1 ripening brown (dark furrows). This should represent a single factor segregation for ripening black and ripening straw along with another single factor segregation for green and brown furrows in the young stage.

---

* The colour in the young stage is given within brackets and letters refer to the lemma colour in plates.

(c) *Piebald (straw H^{pb})* × *Ripening black (dirty furrows H^f).* In a cross studied at Coimbatore (unpublished records) the F_1 was piebald in the young stage and ripening to black. The F_2 gave the following segregation :—

	(Green) Piebald		Dirty in furrows		Total
	Ripening black	Ripening straw	Ripening black	Ripening brown	
Observed ..	234	97	86	36	453 $\chi^2=5\cdot9$ P between 0·2 and 0·1
Calculated 9 : 3 : 3 : 1	255	85	85	28	453

Thus the ripening character shows simple dominance and segregates independent of the piebald pattern.

(d) *Ripening black (E-e, straw H^g ih)* × *Full gold (N-n gold H^f ih* :—In the above cross, Jobithraj [*loc. cit.*] recorded the following frequencies in the F_2 generation ; 290 ripening black : 97 straw : 70 ripening black (dark furrows) : 18 ripening brown (dark furrows) : 91 ripening black (patchy gold) : 18 patchy gold : 26 ripening black (gold) : 9 gold. The ripening black to ripening non-black gives a ratio of 3.4 : 1 which represents monofactorial differences ; phenotypes of straw, dark furrows, patchy gold and gold irrespective of the ripening black factor represent a segregation of the plant of the constitution H^g H^f *Ihih* giving a 9:3:3:1 though the fit is not good.

(e) *Ripening black (green A-a-4)* × *Ripening gold (greenish yellow A-a-2)*. This cross was studied by Narasingarao at the Rice Research Station, Berhampore, (unpublished records) ; dihybrid ratio of 9 green ripening black: 3 green ripening straw: 3 gold ripening black: 1 gold ripening gold was obtained. Thus in the young stage there is segregation only for Ih gene (the straw being H^g Ih and ripening gold H^g ih) and the ripening character is also governed, by a single gene difference in this case. Thus a 9:3:3:1 ratio has resulted when these two ratios interacted

Kato [quoted by Matsura, 1933] crossing a plant with dark grey lemma and another with orange streaked lemma gave in the F_2, 9 dark grey : 3 dark orange streaked: 3 white (pale yellow): 1 orange streaked. It would appear that ripening colours are mixed up with colours in the young stage in this case. Dark grey is apparently ripening black and dark orange streaked, gold ripening black ; white should be straw, and orange, gold according to our present classification. By interaction of the two ratios we should get the same results mentioned by Narasingarao.

(f) *Purple, (L)* × *Ripening tawny (A-a-3).* This cross was studied by Ramiah [1936] who obtained a purple lemma in F_1 and this segregated in the F_2 into 3 dark purple to 1 tawny showing that they differed only in a single gene. If the purple lemma is denoted by AcHp, *tawny* must be *AcH-t*

The ripening purple is always associated with purple lemma colour in the young stage and hence no separate mention need be made of the inheritance of ripening purple character.

(4) *Colour of apiculus*

It is peculiar to find that tips of the lemma and palea are sometimes coloured differently from the body colour of lemma and palea. It is not unusual to find a green, gold or brown lemma having a purple apiculus. Hence the colour in this portion of the lemma has been dealt with separately. The character is often used in schemes of classification of rice types. The most common colour found is the purple of different shades and a pale yellow or brown; some green tips ripen into tawny. Where there is anthocyanin colour in the apiculus it is usual to find colour elsewhere in the plant also, the most common association being the presence of colour in the leaf sheath.

Purple × colourless. Presence of purple colour is dominant to colourless and the following ratios of purple to colourless have been realised by several workers :

3 : 1—Parnell *et al.* [1917], Hector [1922], Mitra *et al.* [1928], Chao [1928, a].

9 : 7—Hector [*loc. cit.*], Mitra *et al.* [1928], Chao [1928, a].

15 : 1—Van der Stok [1908], Hector [*loc. cit.*] Chao *loc. cit.*].

27 : 37—Hector [*loc. cit.*], Lee [1927] Chao [*loc. cit.*].

162 : 94—Chao [*loc. cit.*].

Chao [*loc. cit.*] explained his results by assuming a chromogene gene C and several localisation genes for apiculus colour : viz., three sets of complementary genes A_{pa} and A_{pb}, A_{pa_1} and A_{pc} ; A_{pb} and A_{pc}; an independent gene A_{pl} and one set of duplicate genes A_{p2} and A_{p3} With the present knowledge that two basic complementary genes A and C are necessary for the production of anthocyanin, these ratios may be explained with a slight modification of Chao's hypothesis. A localisation gene A_{p1} by itself gives 3 : 1 ratio of purple to colourless and when each parent possesses two of the three genes A, C and A_{p1} the segregation is a 9 : 7 and when the F_1 is heterozygous for all the three genes 27 : 37 ratio results. A pair of duplicate genes A_{p2} and A_{p3} will explain the 15 : 1 and 162 : 94 ratios ; for when each of the two parents possess the two basic genes and the F_1 is heterozygous only for the two genes A_{3p} and A_{p2}. the 15 : 1 ratio results and when it is heterozygous for all the four genes a 162 : 94 ratio will be obtained. It is possible A may be identical with either A_{p2} or A_{p3}.

Lee [1927] crossing two pale yellow apiculi realised a ratio of 27 purple tips : 9 red tips : 28 pale yellow tips in the F_2. He explained the ratio by supposing three genes C, R and B, the combination CRB giving purple tips, CR red tips and the rest yellow. Jones [1930, a] obtained a ratio 9 : 3 : 4 of purple : red : white apiculus, a dihybrid ratio, where the purple is conditioned by a gene P expressing itself only in the presence of a red gene **R**, the whites being either **P** alone or the double recessive. It may not be possible to explain these ratios involving red apiculus on the same factorial constitution as above. It is not clear if the red is only a shade of purple. Evidently the two cases represent respectively a 9:7 and 3:1 ratio of purple to no purple and there is possibly a purple intensifying factor in addition making light purple (red) into dark purple.

Ripening tawny tip is found to be a simple dominant to non-tawny [Chao, *loc. cit.*]. The gene governing tawny in apiculus is the same which causes ripening tawny in lemma.

(5) *Awn*

The awn in rice, which is the extension of the middle nerve of the lemma is an important morphological part of the grain. Though its role has not been sufficiently studied in rice, the awn is found to have an important physiological function in other cereals. Apart from physiological considerations, the advantage which the awned rices have over the awnless is, they are seldom attacked by birds and are more resistant to insects and wild animals like pigs. Field rats always prefer awnless to awned grains when they have a choice. The awned rices are more difficult to handle and have less weight of grain per equal volume, and from the milling point of view, the awnless types are certainly to be preferred.

Of the several characters, the awn has been found to be most subject to environmental influences. It has been found in Madras, [Anandan, 1933], that closer spacing and manuring increased the percentage of awned grains in the panicle and also the length of awns in certain awned varieties. Sethi *et al.* [1937, b] have recorded in the United Provinces a similar experience with spacing but state that manuring had no effect on awns. Season plays also some part; droughty conditions restrict awn development while shade stimulates. Mendiola [1926] records that increased water supplies augmented awn growth in rice. Though it has not been actually demonstrated, it is certain that awn in rice has an intimate association with the general hardiness of the variety. That this is so, may, in part, be inferred from the fact that many of the rice varieties of *aman* group grown under deep water conditions of Assam, and the *boro* rices which are grown in spring under droughty conditions are fully awned. All the wild rices growing under adverse conditions have fully developed awns.

The existence of awns is an important varietal character. Variations are to be seen in different types both in the length of awns and in their distribution, the former being probably a more dependable basis for identification. The same plant may show longer awns in its later tillers, and in an otherwise awnless form, sterile spikelets are sometimes recorded to develop small awns. In inheritance studies, awning in a plant is best judged by examining its main tiller. The awned varieties can be broadly grouped into three classes based on the length of the awns, Hutchinson and Ramiah [1938]. Though intermediate forms between these three main classes may occur in rice material, it is possible to include them in one or other of these three groups termed respectively tipped, awned and fully awned.

All the available results on inheritance of awning can be summarised as below :

Monohybrid ratio

3 : 1 awned: awnless—Hoshino [1915], Van der Stok [1915], Ramiah (unpublished).

3 : 1 party awned: awnless—Jones [1927].

Dihybrid ratio

9 : 7 awned: awnless—Ramiah [1935], Grant [1935].

15 : 1 awned: awnless—Chao [1928, a], Alam [1931], Mitra and Ganguli [1932], Ramiah (unpublished).

9 : 6 : 1 awned: slightly awned: awnless—Jones [1927], Majid [1939], Ramiah (unpublished).

12 : 3 : 1 awned: partly awned: awnless—Ramiah (unpublished).

Trihybrid ratio

63 : 1 combined group : awnless of all classes of awning—Ikeno [1927] Sethi *et al.* [1937, b], Ramiah (unpublished).

Although the results have been presented in a simplified form, a perusal of the actual papers in which these results have been reported presents great difficulties in that the classification adopted by the authors are all different. Though the length of the awn has been the main criterion in the above groupings, the distribution of the awns also varies and there are reasons to believe that such variations are partly genetic and partly environmental. It is also possible that the different genes involved are either cumulative in their effect as was the case of the trihybrid ratio reported by Sethi or have differential effects as the results of Chao and Ramiah would indicate.

Besides the above, there have been a few cases reported of a more complicated inheritance. There was a case reported by Sethi *et al.* [*loc. cit.*] where the number of genes involved was obviously more than three. Van der Stok has reported of a cross between an awnless type and a weakly awned type in which the F_1 was awnless and a greatly varying F_2 . Nagai [1926] working with a mutant form, Staminoidal sterile, obtained in the segregating progenies three awned groups and one awnless group their proportions being :

Full awned	Medium awned	Rare awned	Awnless
10·95	1	2	2·25

He explained the results on the hypothesis that **N** was a gene for development of awn and **B** a modifier of the length of awn expressing only in the presence of **N** which should give the above four groups in the proportion of 9 : 1 : 2 : 4. The excess of the double dominants and the deficit in the recessive in the actual proportions obtained were interpreted as due to the production of the gametes in different proportions instead of in equal numbers.

Thus from the evidence so far available the awn would appear to be governed (irrespective of the degree of awning) by two complementary genes which may be designated A_{na} and A_{nb} . There are also duplicate or triplicate factors in the inheritance and these may be designated A_{n1}, A_{n2} and A_{n3} . The simple dominant nature of awning in other cases may be governed by any of the above multiple genes. There is also clear evidence that the different genes have differential effect both on the length and the distribution of the awns.

Colour of awn. The main colours of the awn are white or straw, pink (some shades of red) brown and purple. When the apiculus is purple or some shade of red, the awn if present, is of the same colour as the apiculus; and the same factor or factors control in all probability anthocyanin development both in apiculus and in awn. There are few results reported on the inheritance of colour in awns by Indian workers. Most of the published account on the subject is from Japan.

(i) *White × White.* Crossing two colourless or white awns Kato [quoted by Matsura 1933] obtained a red awned F_1 and 9 red : 7 white in F_2. Koch [quoted by Matsura 1933] has reported the appearance of black awned and pink awned forms in a cross between white awned and white awnless types. The colour of the awn evidently depends upon the action of two complementary genes.

(ii) *Red × White.* Both 3:1 Hector [1916] Okada [quoted by Matsura 1933], Kato [quoted by Matsura 1933] and Jones [1930, a] and 9:7 ratio of red: white have been recorded.

These two cases of inheritance would suggest the presence of complementary genes Anr_a and Anr_b and another gene Anr_1 giving simple 3:1 ratio of red : white. Suji and Kitagawa [1926] opine that the white and red colour in lemma apex (apiculus), is governed by a single gene difference (A-a) the simultaneous occurrence of colour in the lemma apex and awn is due to the action of complementary genes A and B.

(iii) *Purple × White.* Sethi *et al.* [1937, b] obtained a monogenic difference between purple and white awns. In one cross studied at Coimbatore (unpublished records) between a full purple awned type and an awnless type, the F_1 was purple. In the F_2 the depth of colour in the apiculus varied, two groups being made out, one with definite purple apiculus and the other with very light purple apiculus. The colour in the awns also varied according to the apiculus colour, those with purple apiculus having purple awns and those with light purple apiculus white awns. The ratios obtained were :

Apiculus purple, purple awns.	856
Apiculus light purple, white awns.	309.

The above represents only a single gene segregation and this was confirmed by the F_3 behaviour. The gene may be designated *Anp*; it may be the same as Ap_1 governing apiculus colour.

Kato [quoted by Matsura 1933] got in the F_2 generation of a similar cross, 9 purple awned: 3 red awned and 4 white awned. Kato drew up a scheme which included a chromogen gene *C*, a red gene *R* working only in the presence of *C* and a purple gene *B* expressing only in the presence of *C* and *R*, (= A and C). Jones [1930, a] got a similar ratio as that of Kato, purple in this case being dark bluish black. This would also explain the simple 3:1 ratio of purple to red obtained by Nagai [1921].

(iv) *Brown* × *Colourless*. In this cross Nagai [*loc. cit.*] obtained a red awned F_1 and the F_2 segregation resulted in a ratio of 9 red : 3 brown and 4 colourless and he adopted the same scheme as Kato but with the additional gene *O* which modifies the action of *C* to produce brown pigment and believed that *C* and *O* are either completely linked or they form a single gene complex. Thus in his material :

CORB would be purple
CORb would be red
$\left.\begin{array}{l} COrB \\ COrb \end{array}\right\}$ would be brown

other combinations without *CO* would be white.

(v) *Black X Green*. Hoshino [1915]has reported that black awn is dominant to green but no F_2 segregation has been recorded. Black probably represents only dark purple.

Secondary awning in rice

A peculiar phenomenon has been recorded by Piacco [1937, b] with regard to awning. Certain varieties of rice used in his experiments have primary panicles which are completely awnless while the secondary panicles may be slightly awned and this he termed as 'secondary awning'. He sowed grain from awnless primary and awned secondary panicles separately, all the secondary panicles gave awned progeny while the primary panicles, awnless progeny. He again sowed grain from a number of awned secondary panicles along with grain from awnless primary panicles as controls. All the resultant plants had awnless primary panicles while the secondary panicles were either awned or awnless. It was concluded by him that 'secondary awning' was hereditary and that a retarded inversion of the valency of the character pair, awnless and awned, by which the recessive could become dominant, was responsible for this phenomenon. Some workers observe that now and then the secondary branches of the same panicle produce awns while the primary ones are without them. This difference it is explained may be due to differences in nutrient of soil solution at different periods or the climatic complexes at different times.

Double awned spikelets

Kadam *et al.* [1936] have recorded an interesting tetratalogical case in the awning of rice. In a culture of hybrid origin breeding pure, a few plants showed double awned spikelets confined to the upper part of the panicle branch. There was variation in the double awned spikelets in different panicles of the same plant ; twenty nine plants had double awns and ten plants were single awned. The double awned plants were all sterile.

(6) *Pistil*

(i) *Multiple pistil*. Almost all the cultivated varieties of rice contain a single ovary, but one variety from Bengal which, first described by Prain, contains more than one ovary in most of the spikelets in a panicle. This variety is named *O. sativa* var *plena*, Prain, and is popularly known as 'double grained rice'. Shen [1938] records that in the double grained rice, the pistils in each spikelet varied from three to nine and each pistil had one ovary, one style and two stigmas as in the normal rice. The maximum number of rices in the grain is, however, never more than three and they are odd shaped.

Extensive studies were made of crosses between this variety and a number of cultivated varieties at Coimbatore, [Parthasarathy, 1935] to find out the inheritance of this character and its association, if any, with other characters such as clustering of spikelets, long glumes, glutinous endosperm, purple lemma and palea, pericarp colour, grain size and sterility. The multi-pistillate condition was found to be a simple recessive to the normal. This has been later confirmed by other workers. The multi-pistillate condition is controlled by a gene which may be designated **mp**, the single pistillate form being **Mp**. It was found that while the multi-pistillate character was independent of the first characters mentioned above there was found to exist some amount of genetic association between multiple pistil and larger grain size; the multi-pistillate condition was also found associated with greater spikelet sterility.

(ii) *Stigma colour*. The colour in the stigma belongs again to the anthocyanin group, the depth of colour depending upon the development of the pigment. Under high concentration the pigment in the stigma appears almost black; at the other extreme we may have only a few of the stigmatic hairs speckled with purple. The early work at Coimbatore suggested the possibility of a single gene controlling anthocyanin colour in leaf axil and stigma. That this was only a case of very close linkage was later proved by Parnell *et al.* [1922] as definite crossovers were obtained.

With regard to stigma colour the following types of segregation of purple to colourless have so far been reported :

3 : 1 Nagai [1921], Parnell *et al.* [1922], Hector [1922], Mitra *et al.* [1928], Chao [1928, a].

9 : 7 Chao [1928, a], Mitra *et al.* [loc. cit.].

15 : 1 Van der Stock [1910].

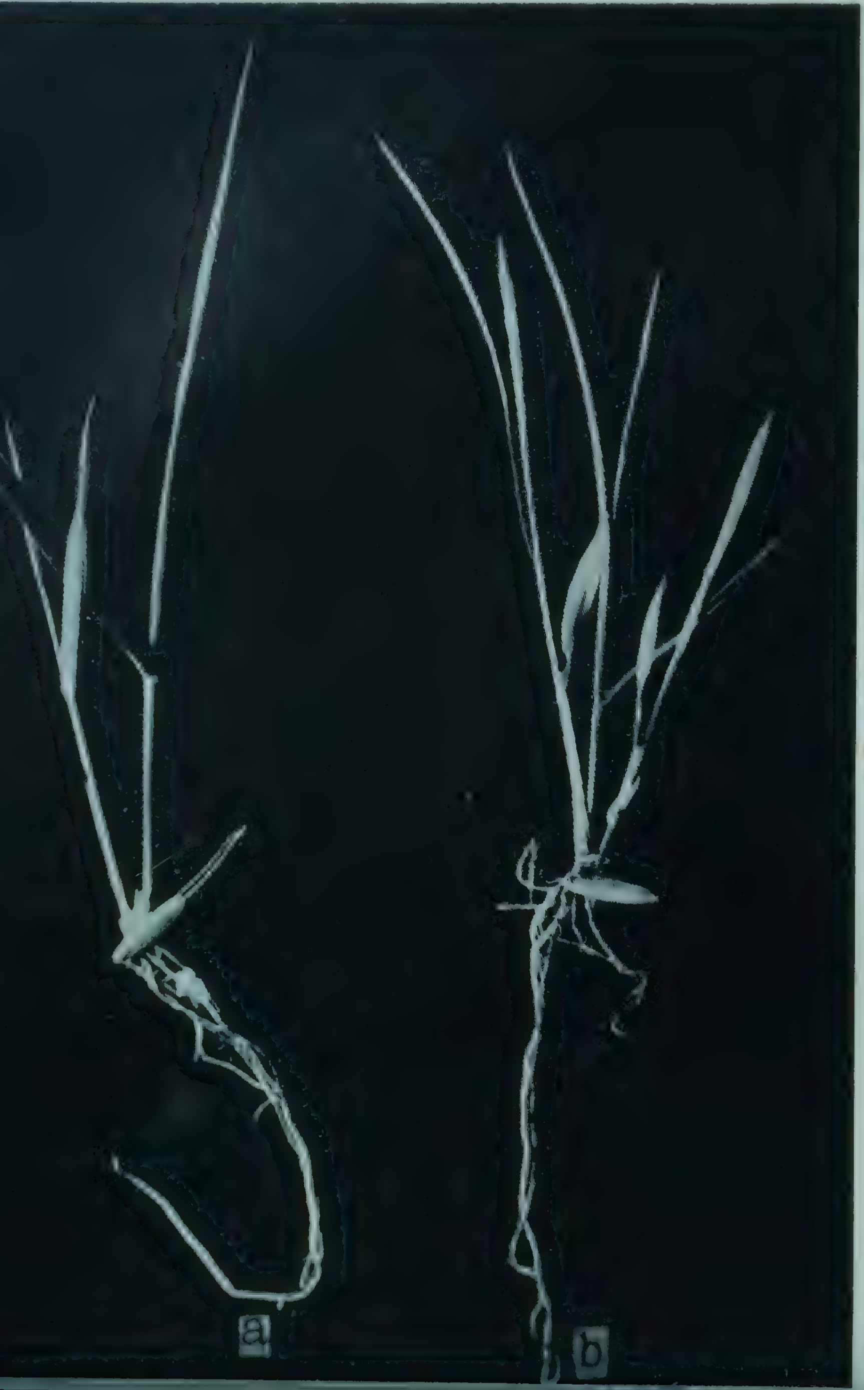
27 : 37 Hector [*loc. cit.*].

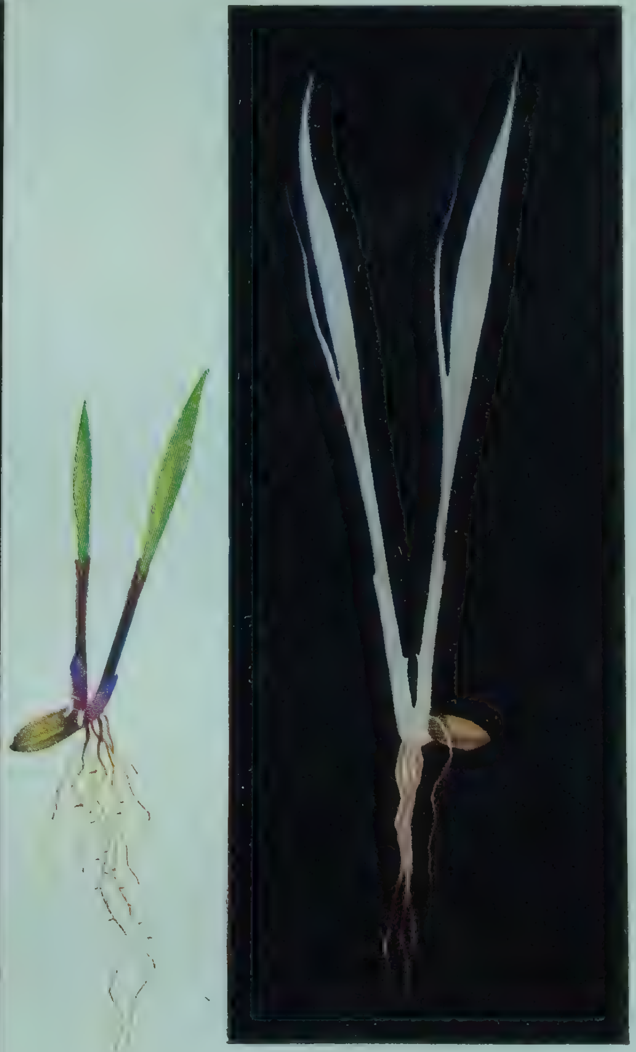
81 : 175 Hector [*loc. cit.*].

The above ratios could be explained on similar assumptions as for the apiculus colour. In conjuction with two basic pigment genes **A** and **C** a gene $\mathbf{Sp}_1$ explains the 3 : 1 and 9 : 7 and 27 : 37 ratios. A pair of duplicate genes $\mathbf{Sp}_2$ and $\mathbf{Sp}_3$ is concerned in the ratios 15 : 1, and the ratio 81 : 175 is governed by a pair of complementary genes, $\mathbf{Sp}_a$ and $\mathbf{Sp}_b$ working along with **A** and **C**. It is possible $\mathbf{Sp}_1$ may be identical with either $\mathbf{Sp}_2$ or $\mathbf{Sp}_3$.

The results of a cross between a dark purple stigma and light purple stigma obtained at Coimbatore (unpublished records) may be mentioned. While the dark stigma proved a simple dominant over the light stigma its association with other pigment characters proved interesting. The parent with the light stigma had light purple leaf axil, dark purple internode, purple lemma while the parent with the dark stigma had dark axil, light purple internode, green lemma with purple apiculus. The F had dark axil, dark

Plate XIX





b

a

Fig. 2

a. A green twin. b. An albino twin.

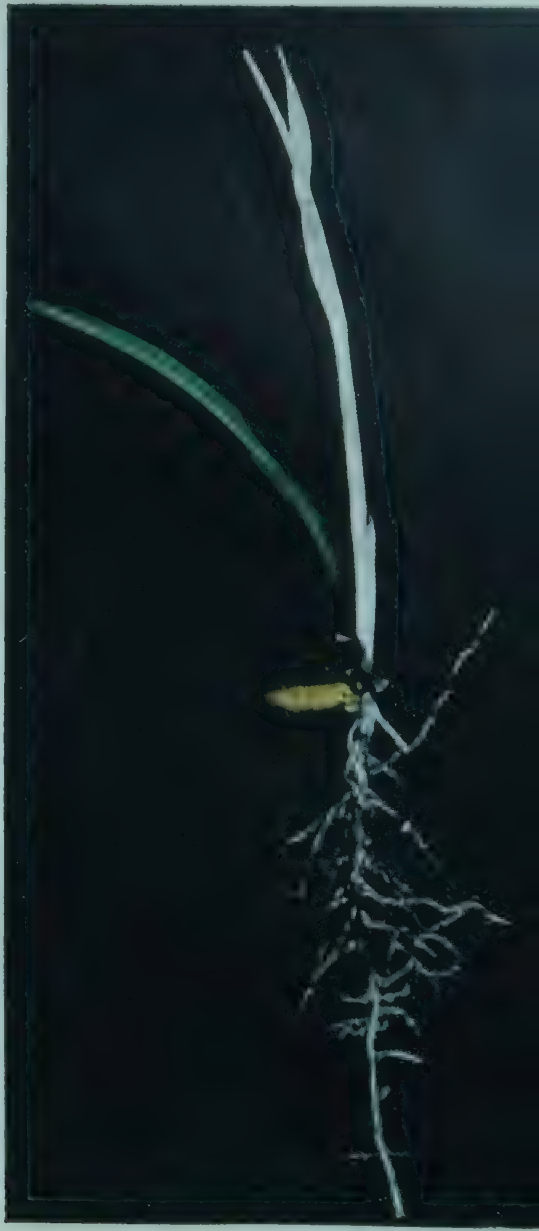


Fig. 3

An albino and a green seedling from a single seed.

internode, purple lemma and dark stigma. The F_2 gave only three groups as shown below :

dark internode purple lemma	dark internode purple lemma	light purple internode green lemma with purple apiculus
light axil	dark axil	dark axil
light stigma	dark stigma	dark stigma
630	1,248	570

The ratios no doubt represent a 1:2:1 several characters going together as a group.

(iii) *Polyembryony.* Polyembryony which involves the obtaining of more than one plant from a single seed is a rare phenomenon in the *Gramineae* in general and still rarer in rice. Only a few cases of polyembryony had been recorded in rice until 1934. Rodrigo [1925, b] found that one seed of a rice variety had produced two plumules and two primary radicles on germination. Jones [1928] found identical twins derived from one fertilised egg and Komuro [1922] derived a rice seed which upon germination produced two plumules. In the material investigated by Ramiah *et al.* [1935, b] at Coimbatore, several interesting cases of polyembryony were recorded. One pure line, Geb. 24, was shown to exhibit this feature consistently once in every thousand seeds. Although seeds giving rise to twins and sometimes even to triplets (recorded for the first time in rice) were obtained in this pure line, hybrid material showed more frequent cases of polyembryony and there were evidences to show that it might be a hereditary character. A pure line has been isolated at Coimbatore which throws out twin seedlings almost invariably. The cases of twins resulting from polyembryony investigated at Coimbatore showed that they were either genetically identical or genetically different. Of the latter, one set included a haploid and a diploid plant from a pure line progeny, and another a green and an albino from a hybrid progeny (Plate XIX). In the latter case the green bred true in the next generation.

The breeding behaviour of the homozygous allelomorphic twins throw some light on the source of polyembryony in rice. It suggests that the development of two embryosacs in one ovule might have contributed to the origin of the twins. Such a condition where more than one embryosac develops in one ovule has been actually observed by Kuwada [1910].

Webber [1940] suggests that euploid twinning, such as haploid and diploid, may arise from single embryosac, and cytologically similar twins from multiple fertilisation of egg, synergids and antipodal cells. Kappert [1933] in an elaborate study of polyembryony in flax concludes that polyembryony is a recessive character probably conditioned by a series of multiple allelormorphs. He suggests that in hybridisation, suitable recombination of recessive multiple factors from various strains occurs as a consequence of which polyembryony segregates out in certain lines.

(7) *Anther length*

The cultivated varieties of rice (*O. sativa*) have normal anthers whereas in a wild species, *Oryza longistaminata* which is common in the swamps of Orissa (India) and Africa the anthers are very much longer than in cultivated rice so as to be easily differentiated by the naked eye. A study of the anther lengths was made in a cross between the wild species and a cultivated rice at the Rice Research Station, Berhampur, by Narasingarao (unpublished records). The range of anther length in the cultivated variety was between 2.6 mm. to 3.0 mm. and that in the wild variety between 4.4 to 5.0 mm. The F_1 had a mean anther length somewhat less than the mean of the two parents. The F_2 progeny showed a continuous gradation of anther lengths covering the entire range of the two parents with a high coefficient of variability. There was an indication of a break at the 3.6 mm. class, but it was not definite. Thirtysix F_3 families were raised and the coefficient of variation of these families for length of anthers varied from 3 to 12, twentyfour families having a C.V. less than 4, the C.V. of the normal parent. It would thus appear that a fair percentage of F_3 families have bred true for anther length. Though in most cases the mean of the F_3 progeny was slightly less than the parental F_2 value, the coefficient of correlation between the F_2 and F_3 lengths was as high as +0.98. The results tend to show that the genes governing anther length may not be many, probably not more than two, and there are indications to show that normal shorter anther is recessive to the long anther of the wild species.

6. GRAIN CHARACTERS

(A) Rice grain

(1) *Colour of husk*

The brightness of the grain colours is a factor to which trade attaches some importance. A thinner husk with a thin pericarp and white kernel inside would impart a brighter colour to the grain than a thicker husk or a kernel with red pericarp, and evidently rices with thinner husk mills better and also gives a product of better quality. The inheritance of the hull colours has already been dealt with under ripening characters of lemma and palea.

Apart from the size and shape of the grain dealt with later, the thickness of the husk does vary among different rices. The percentage of shelled rice to grain in husk is an important economic character and this is largely influenced by the thickness of the husk. Determination of the percentage by weight of shelled but unpolished rice to whole grain among 400 pure line collections at Coimbatore has shown that this varies between sixtyfive to eighty. It is an important character and no inheritance studies on the thickness of husk nor on the relationship between colour of husk and its thickness have so far been undertaken anywhere. Some associations have been reported between the colour of the husk in ripe grain and other physiological characters. It was shown by Lord [1929, b] that rices with dark coloured lemma and palea took longer time for germination than rices with light coloured lemma and palea. It was established by Parnell *et al.* [1917] that ripening gold lemma was associated with particular grain size, the grain with this character being finer than the one with either brown furrows or dark gold colour.

Kato [quoted by Matsura, 1933] obtained a monogenic difference between easy and tough shelling ; tough shelling gene may be designated as Tl.

(2) *Size and shape*

(a) *General.*

One of the most striking feature of cultivated rices is the enormous variation in the size and shape of grain. There must be a large number of genes concerned to produce this variation and the genic analysis of this variation presents difficulties. The size and shape of grain has been used by almost every botanist as one of the diagnostic characters in classification. Size and sometimes shape of grain are very important from the trade point of view. In addition, a uniform size and shape in a commercial sample is an important criterion as the milling properties depend upon it. The length, breadth and thickness of the grain or kernell can easily be measured by a pair of callipers or a dial micrometer though, occasionally, thickness is omitted from such measurements as it does not vary quite so much among varieties. The shape can also be described, though not definitely, by an examination of the curvatures of lemma and palea as has been done by Graham [1913]. The size of the rice kernel inside follows the variation in size of the unhusked grain with few exceptions and hence the latter may be taken as an index of the kernel size.

Before analysing the genetic factors controlling the size of grain the influence of environmental conditions on this important character may be detailed. Tin [1936] is of the opinion that harvesting date affects grain size, the later the harvest the shorter and narrower being the grain. Fertilisers such as ammonium sulphate, which cause large yield increases tend to give significant increases in grain size also. Grain size has been shown by him to differ significantly within a pure line grown at different places. The effect of soil on grain size is well recognised as cultivators generally complain of fine varieties grown in well drained porous soils becoming coarser when grown in heavier and richer deltaic areas, and Coimbatore workers have often come across this experience. The effect of manuring, it would appear, has not been studied thoroughly but it is considered by Ramiah that in rice, manuring does not produce such great variation in grain size as in wheat [Engledow and Ramiah, 1930] and other cereals. It may be mentioned that all grains in a panicle are not of the same size; it generally decreases from the tip of the panicle down below, the average length corresponding to those situated in the middle of the panicle. The size of the sample to be taken for determining the length, breadth measurements of grains has been investigated by different workers. Parnell was of the opinion that the measurement of top three grains gives a fair representation of the grain size of the ear. Lord [1929, a] recommended a minimum of 20 grains for such measurements. Ramiah and Parthasarathy [1933] found that a sample of six grains taken either from the top or the middle of the panicle gave as good an estimation as a composite 36 grain sample. They have also reported that no significant variation was found between the size of grain on different tillers of the same plant. Tin [*loc. cit.*] wants at least 100 grains to be measured to give a correct picture in a pure line. In inheritance studies it is important to grow the parents and the F_1s along with the F_2 close together every season to obviate differential effects of season and soil.

(b) *Inheritance studies*

(1) *Size*

(i) *Length.* The length of grain (rice in husk) has been found to vary from 5.3 mm. to 11.5 mm. among types grown and studied at the Paddy Breeding Station, Coimbatore. Genetic stocks at Central Rice Research Institute has now a type with 14.2 mm. length, the longest so far met with. Parnell *et al.* [1917] in a cross between a dwarf variety with small, round grain and a normal type with medium size of grain obtained a clear-cut 3:1 of normal length to shorter length, but in this case the grain size was controlled by the same gene responsible for dwarfism. Two crosses studied by Ramiah *et al.* [1931] between a short round grain with a mean length of 5.81 mm. and a long grain of over 10 mm. gave two definite groups, with a clear minimum frequency point in F_2. These two groups gave frequencies approximating to 3 short round to 1 long. The mean lengths of the two extracted homozygous groups did not correspond to the two parents used in the cross. This phenomenon explained by Engledow [1923] as 'shift' is now known to be due to minor modifiers. The coefficient of variation was still high in the homozygous long grained group and it was possible to extract pure breeding forms with various mean intermediate lengths reaching the limit of the long parent.

Ramiah and Parthasarathy [1933] have later reported results of two crosses where the parents differed only in length of the spikelet, 5.95 and 11.11 mm., with almost similar breadths and shape. The F_2 distribution here covered the whole range of the parental limits, giving a definite bimodal curve. All the F_2 plants were studied in the F_3 generation and it was found that 49 families, forming about ⅛th of the total population, were pure breeding for grain size.

They explained that in this cross, where grain length was not modified by shape, the inheritance of length was governed by the interaction of three genes, $\mathbf{K}_1$, $\mathbf{K}_2$ and $\mathbf{K}_3$ though it was not possible to determine the extent to which each of these genes modified the length. Mitra and Ganguli [1938] have reported the occurrence of 3:1 ratio of short to long in an F_2 and the existence of variation within the two groups of short and long due to modifiers. Grant [1938] studied two crosses, one between two *indica* races and another between an *indica* and a *japonica* race and found that size as well as shape of grain were governed by multiple genes. The results, however, confirmed the general dominance of short over long in length of grain. Alam [1939] obtained a 3:1 ratio of short to medium in the F_2 generation of a cross between short narrow and medium narrow grains and a ratio of 9:7 of long to medium grain size in a cross between the corresponding types.

Dave [1939] had studied a number of crosses between parents which he classed as very short (mean 4.38 mm.), short (mean 5.47 mm.), medium (mean 6.34 mm.) and long (mean 7.13 mm.). The length of the kernel and not that of the grain in husk was taken into consideration in these crosses. The F_1 was intermediate in every case and the F_2 segregations he obtained are indicated below :

Cross	*Segregation in F_2*
1. Very short × short.	3. Short: 1 very short
2. Very short × medium.	9 short: 6 very short: 1 medium in one cross and 3 short to 1 very short in another.
3. Short × medium.	3 medium to 1 short.
4. Medium × long.	3 long to 1 medium.
5. Short × long.	A long drawn out range, the frequencies giving a normal curve.

It is recorded that the F_3 results confirmed the F_2 segregation in every case. It has to be mentioned, however, that in the results reported of these crosses, the F_2 frequencies are not large and the point of minimum frequency is also not definite to justify the groupings on either side of this point. The above results showed generally that the longer length behaves as a simple dominant over the next lower length and this behaviour is contrary to results reported by other workers. In the last cross, however, the inheritance is of the polygenic type.

Bhide [1926], Majid [1939] and Chakravarty [1939], all report that grain length in rice was a polygenic character.

In the inheritance studies of Chao [1928, a] where short length was a simple dominant over long, the short length was associated with a round shape, the same as in the cross mentioned under Coimbatore earlier. Tang [1937] crossed two varieties with grains 8.2 and 12.95 mm. in length and from the F_2 and F_3 data concluded that the two parental stocks differed in a series of genes for dominance. Jack [1932] has reported that long grain was dominant to short, which is a result in variance with the several cases mentioned above.

It would thus appear that the length of grain is governed by multiple genes and the type of F_2 results one gets will depend on the parental differences with regard to these. Wherever a good 3:1 ratio of short grain to long grain occurs, it is found that the short grain has a characteristic round shape. Even where the inheritance is of the polygenic type there is an indication of short length being dominant over the long grain.

(ii) *Breadth.* The ' breadth ' of grain is of even greater importance in determining the size or the grain shape. In varietal collections running over several hundred types, grown and studied at Coimbatore, the breadth is found to vary from 1.9 mm. to 3.7 mm. and the types could be broadly classed as narrow (1.9 mm. to 2.2 mm.), medium (from 2.3 mm. to 3.0 mm.) and broad (3.1 mm. to 3.7 mm.).

Crosses were studied by Ramiah and Parthasarathy [*loc. cit.*] between two varieties (T.33 × T.32) which differed in breadth, length remaining constant and also between two varieties which differed both in length and breadth (T.33 × T.25). The F_1s were intermediate in breadth and the F_2 in both crosses gave a continuous range, the frequencies giving a curve with almost the same means as the F_1s but with a higher coefficient of variation. The authors have, therefore, suggested that the inheritance of breadth as in the case of length was of the polygenic type. Grant [1937] observed similar behaviour in crosses between Burmese varieties and there were indications of 'thinness' or smaller width being dominant over 'broadness' or larger width in one case and the reverse of it in another. In the case of the cross between the *Blue rose* (American) and Nagasein (Burma), such dominance was, however, not indicated. Mitra and Ganguli [*loc. cit.*] obtained only normal distribution with regard to width of grain in F_2 and F_3 generations though, there was a clear segregation of 3:1 with regard to the length, and this led them to conclude that the inheritance of breadth was of the polygenic type. Majid [*loc. cit.*] has reported a cross where the width of grain in F_1 was intermediate between the parents and the F_2 segregation in this case was explainable on a digenic basis.

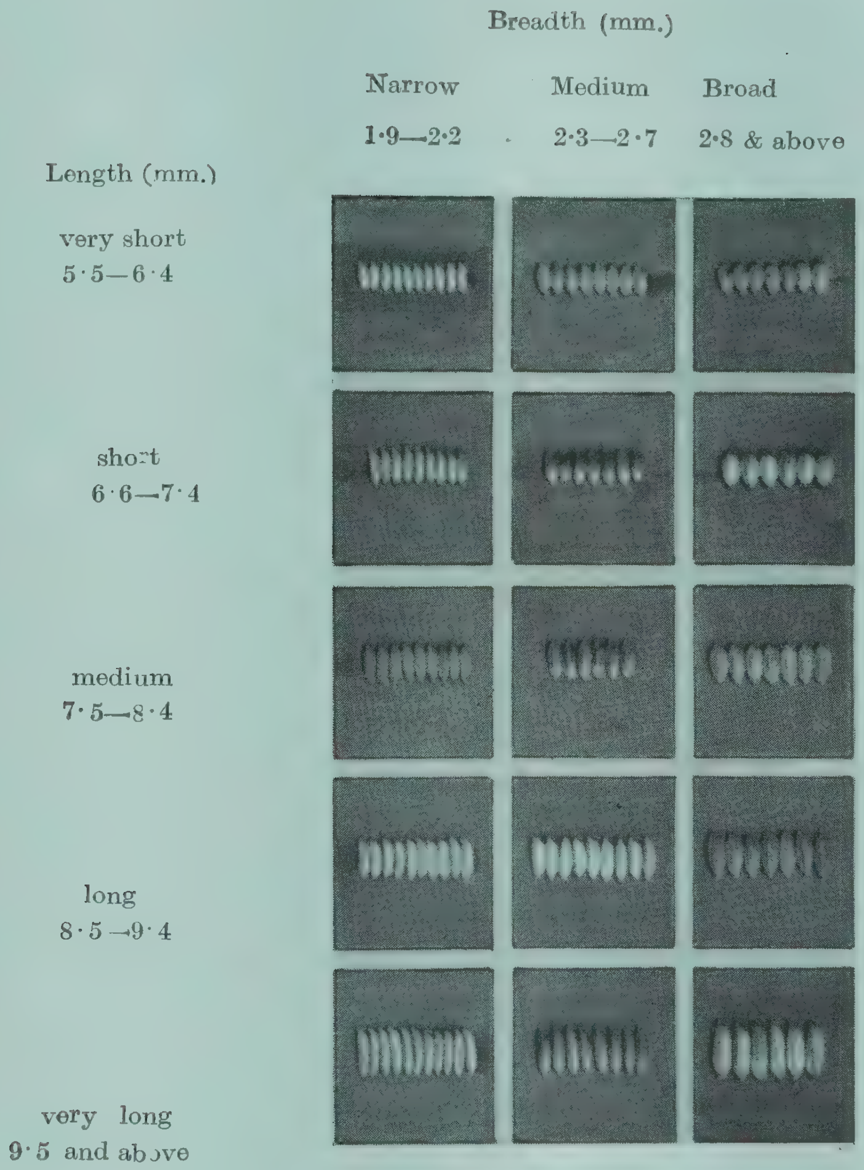
Dave [*loc. cit.*] has reported that in a cross between a medium variety (mean breadth 2·53 mm.) and a coarse one (mean breadth 3.07 mm.) the F_1 was intermediate (mean 2.76 mm.). In the F_2, two distinct groups could be made out; a medium group in which breadth ranged from 2.53 to 2.87 mm. and another coarse group in which the breadth ranged from 2.91 to 3.16 mm. Grouping the frequencies on either side of 2.88 mm., the minimum frequency class, he got a 3 : 1 ratio of medium to coarse. The F_3 behaviour confirmed the recessive nature of the coarse type, the medium either breeding pure or segregating into 3 : 1 of medium to coarse like the F_2. A similar behaviour was observed by him with regard to a cross between medium (mean 2.53 mm.) and a fine rice (mean 2.06 mm.) which gave a bimodal curve in F_2 with a ratio of 3 : 1 of medium to fine. The fine group had a breadth range of 2.03 to 2.25 mm. and the medium, a range of 2.28 to 2.64 mm. Thus according to Dave, grain with a medium width is dominant over coarse grain and again the medium grain is dominant over fine grain. It would appear doubtful whether the inheritance could be as simple as has been explained by Dave. As mentioned already, in his results the frequencies were neither large nor the point of minimum frequency very definite.

(iii) *Association between length and breadth of grain.* As has been mentioned already the range of variation in length and breadth of the several rice varieties at Coimbatore was from 5.3 to 11.5 mm. and from 1.9 to 3.7 mm. respectively (Plate XX). Though an enormous number of combinations of the various lengths and breadths are possible, actually such a large number is not found in nature. It is found that in a joint tabulation of length and breadth dimensions, there are very few types in the extreme classes. This should suggest that there is an association between the length of grain and its breadth. When the varieties referred to above are classified and grouped according to the length and length/breadth (L/B) ratio, it is found that there is a definite positive correlation between them ($r = + 0.60 \pm 0.18$) indicating that long grains tend to be narrow and short grains tend to be broad. The coefficient of correlation between length and length/breadth calculated in two pure lines T.55 and T.293 by Ramiah and Parthasarathy [*loc. cit.*] is also positive and fairly high. The F_2 progeny of the cross between these two parents already referred to, having a greater variability as regards length of grain gave a coefficient of correlation of + 0.74 ± 0.02 between length and length/breadth ratio. In another cross where the parents differed both in length and breadth there was a definite correspondence between the length variation and the distribution of length/breadth in the F_2 generation, r being + 0.639 ± 0.18. It may, therefore, be concluded that the genes controlling length and those controlling breadth, though different, are not altogether independent.

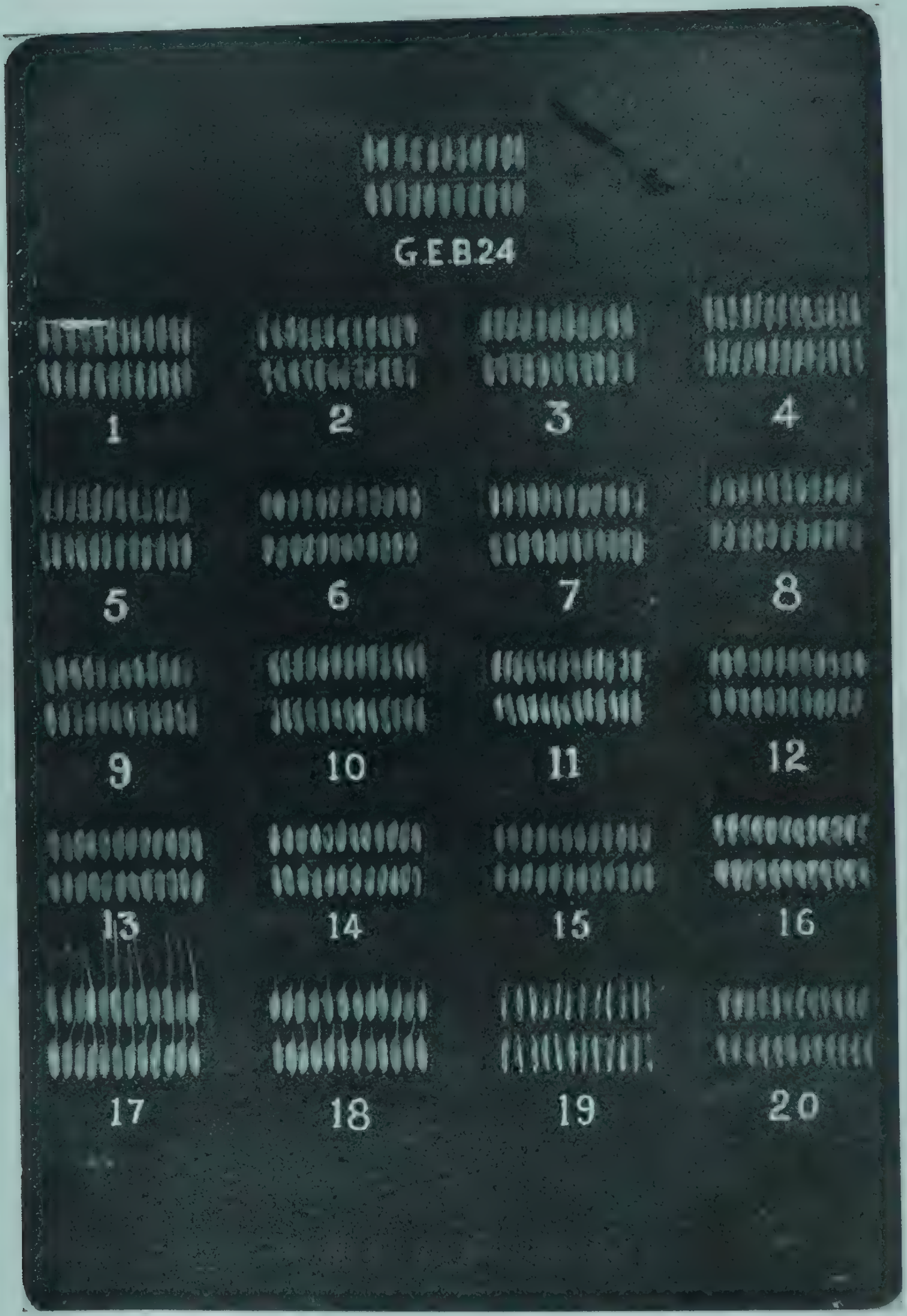
Mitra and Ganguli [*loc. cit.*] and Majid [*loc. cit.*] did not observe the above association in their crosses in Assam varieties reported earlier. But recently Ganguli [1940] from the same place has recorded that though length and breadth were inherited as separate characters, a certain amount of relationship was observed between them in the varieties he studied, thus confirming Coimbatore results.

(iv) *Thickness.* Thickness which is the least of the three dimensions of the rice grain, does not vary to a great extent in the several varieties of

PLATE XX


Breadth (mm.)
Narrow
1·9—2·2
Medium
2·3—2·7
Broad
2·8 & above
Length (mm.)
very short
5·5—6·4
short
6·6—7·4
medium
7·5—8·4
long
8·5—9·4
very long
9·5 and above

Variations in grain size Coimbatore.


G.E.B.24
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Variations in grain size and shape induced by X-ray. (Coimhatore)

Parent at the top Geb. 24.

rice. The range in thickness observed among Coimbatore types varied from 1.5 to 2.2 mm.

This character has not been studied intensively. Majid [*loc. cit.*] has reported that thickness is governed by a number of genes and it is not possible to determine the exact number. He has, however, observed a "shift" towards the narrow parent in the F_2 generation.

(2) *Shape*

As has been pointed out already the shape of rice is governed by the ratio of length to breadth and the length of the grain. The larger this ratio, the more slender is the grain. As it is found that there is a definite association between the length and ratio of length to breadth, it follows that the longer the grain, the finer it tends to be. Thus it may be argued that the genes governing length do also partly govern the shape of the grain. Graham [*loc. cit.*] recognised five shapes in the varieties of the Central Provinces he was working with, based upon an arbitrary idea of the curvatures of lemma and palea. The size of the grain was also divided into four groups; long, where length/breadth = 4; fine, length/breadth = 3; coarse, length/breadth = 2; round, length/breadth = less than 2.

Alam [*loc. cit.*] has advocated the use of an index 'e' which is expressed by the ratio weight of 1,000 grain/length of the grain. He claims that this index called 'grain quality index' gives a good indication of the fineness or otherwise of the sample. The index is said to be definite, accurate and easy to work with. The classes are distinct and do not merge one with the other. Using this index he distinguished six grades among the Bihar rices as shown below :

Grain quality index in Sabour (Bihar) rices

Class of rice	Range in length of rice kernel, mm.	Range in grain quality index 'e'.
Fine	5·9 to 7·3	2·2 to 2·6
Short fine	3·7 to 5·3	1·6 to 2·1
Medium	5·5 to 7·8	2·6 to 3·1
Short medium	4·4 to 5·5	2·6 to 3·1
Coarse	5·5 to 6·8	3·1 to 4·1
Short coarse	5·0 to 5·4	3·1 to 4·5

The round shape is found to be generally dominant to the long oval shape. The gene governing this round shape may be designated **Kr**. Van der Stok [quoted by Matsura, 1933] had studied the inheritance of this character between two varieties belonging to the *minuta* or round grain group and the *communis* or the fine grain group and got a 1:2:1 of *minuta* : Inter (medium): *communis*. Terao and Kato's [1922] large grained mutation behaved as a simple recessive to the normal.

Morinaga [1940] has recorded interesting studies on the size and form of caryopses and their mode of inheritance. If the lemma and palea are cut off soon after anthesis, the rice caryopses develop into a peculiar shape that is characteristic of the variety dealt with. These free caryopses were claw shaped in the *indica* group and straight in the *japonica* group. Free caryopses of the *japonica* varieties gave a strong colour reaction with phenol, whereas normal caryopses do not show this reaction in any of the varieties tested. The free caryopses have thicker pericarps than the normal ones. In the reciprocal crosses between types with caryopses of different sizes and shapes, the F_1 free caryopses always resembled the maternal type. In the F_2 there were no essential differences between reciprocal hybrids and the variation curves for the free caryopses were bi or trimodal, whereas the curves for the normal F_2 and the F_1 and parental caryopses were unimodal. He considers that Mendelian segregation occurs but that its expression is limited to some extent by the pericarp membrane. In normal caryopses it is entirely repressed by the mechanical effect of the enclosing lemma and palea and pericarp. The character of phenol colouring behaved as a partial dominant. As the pericarp is the tissue affected, the F_1 caryopses were of the maternal type; the F_2 acted intermediately.

(3) *Weight of grain*

A point of interest and one of economical importance is that the weight of the rice grain varies according to its size and shape, the coarse type being naturally heavier. This had been recorded by Parnell *et al.* [1922] in several families segregating for grain shape, in which the weight was associated with particular grain colours.

(4) *Abnormalities in size and shape*

A large number of variations in size and shape of the rice grain was obtained by exposing the dry seed of a pure line to X-rays at the Paddy Breeding Station, Coimbatore (Plate XXI). They included such shapes as 'long and narrow'. 'elongated', 'small grain', 'stumpy', etc. The inheritance of a large number of these mutations was either not intelligible or not fully worked out [Ramiah and Parthasarathy, 1938].

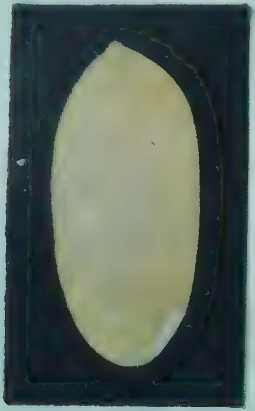
(B) Kernel

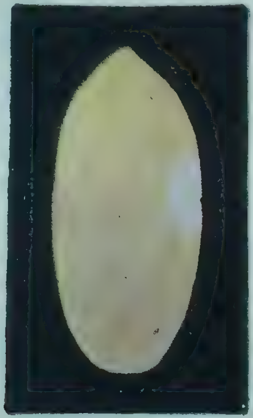
(1) *Colour of kernel pericarp*

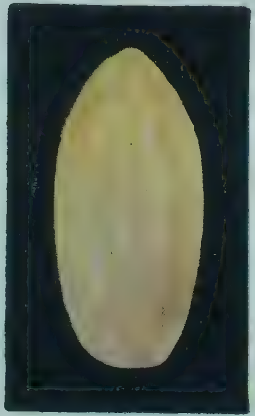
The colour in the rice kernel is confined to the pericarp layer in the mature stage; the endosperm of all the rices is white. The endosperm of a variety of rice from Siam called *Birurutong* was said to be purple, but a critical examination of the type at Coimbatore revealed that the dark pericarp colour was only refracted through the translucent endosperm giving it a false colour which however disappeared when the pericarp was removed. The term 'coloured rices' is not scientifically correct but by common usage it has come to mean the colour in the seed coat (pericap) and in the description that follows coloured rice would be taken to convey the same meaning. The colours in rices most commonly occurring are white and various shades of red; purple (almost black) rices are rather uncommon and such colours as gold, deep brown or grey brown have also occurred though only in hybrid cultures and these are of genetic interest only, (Plate XXII).

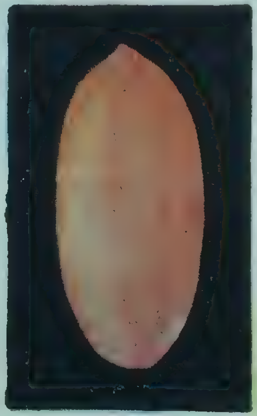
Plate XXII

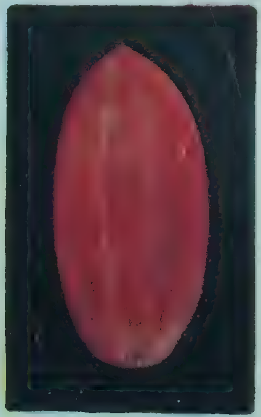
RICE COLOURS

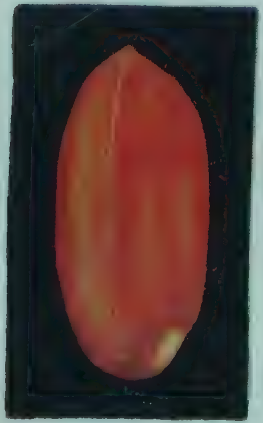

1

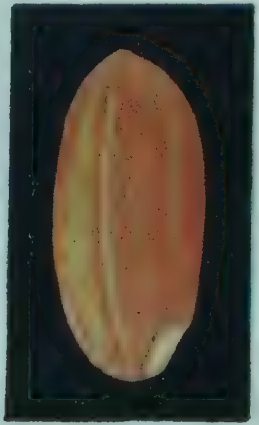

2

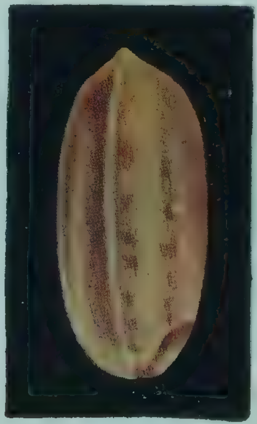

3

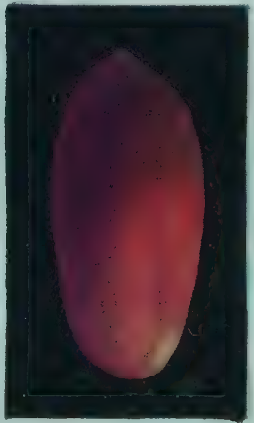

4

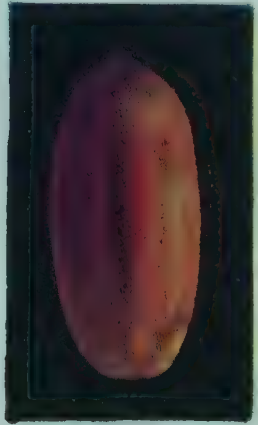

5

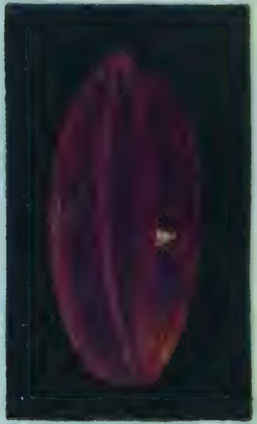

6


7


8


9


10


11

: colour of rice is an important economic character. The rice consum- public has cultivated a preference for white rice though, from nutritional nt of view, red rices should be preferable. The presence of red grain in ommercial sample is a detraction and it valued less than a sample free n it. It is not known definitely to what chemical compound the colour rice is due, but it has been suggested by Kato and Ishikawa [1921] that red and yellow colours were due to protocyans; purple rices owe their our to the products of anthocyan group as they impart purple colour to water in which they are soaked.

Due to its economic importance rice colour has been studied by a nber of workers in India and abroad. Most of these studies relate to inheritance of red colour only.

(a) *White × white.* Mitra et al. [1928] obtained a ratio of 9 red : 7 ite rice in the F_2 of a cross between two white rices indicating that two nplementary genes were responsible for the production of red. The red e was in all probability light red.

(b) *Light red × white.* Alam [1940] in a cross between a variety with ht red rice and another with white (somewhat dirty) rice got a very light l F_1 which segregated into 1 light red : 2 very light red : 1 white in the . A monogenic difference was observed in other crosses between light l and white, white being recessive. A simple ratio of 3 light red to 1 ite was observed in crosses between light red and white riced varieties bithraj, 1936].

(c) *Light red × light red.* In this cross [Jobithraj, loc. cit.], the F_1 s dark red and the F_2 segregated into 9 dark red : 7 light red, suggesting it the dark red depended on two complementary genes for its expression. e genes controlling the light red character may be designated as Pr_a and .

(d) *Red × white.* A monogenic difference between red and white has en reported by several workers; [Van der Stok, quoted by Matsura, 33], Hector [1913], Jacobson [loc. cit.], Thompstone [1915], Parnell et al. 917], Yamaguti [1918], Frazwirth quoted by Matsura [1933], Chao 928, a], Jobithraj [loc. cit] and Majid [1939].

Ramiah and Mudaliar [1935] obtained a digenic ratio of 15:1 of red white in a cross between red and white rice showing that duplicate fac- s were concerned in the production of red colour, and the F_3 results nfirmed the F_2 ratios. In a cross between dark red and white rice tra and Ganguli [1932] obtained a ratio of 12 red : 3 amber : 1 white the F_2 which can be taken as a modification of 15 red : 1 white. Chao c. cit.] had obtained also a ratio of 15:1 dark red to white in the F_2 of cross between a red and a white riced variety. The genes governing dark l may, therefore, be designated **Pr_1** *and* **Pr_2**.

Taking all the available data into consideration it is possible that two ies of alleles affecting pericarp colour are involved. These two series y be represented as below :

Series 1 $(Pr_2)\ Pr_1$ $(Pr_2)\ Pr_a$ $(Pr_2)\ pr_1$

Series 2 (Pr_1) Pr_a $\underline{pr_2\ (Pr_1)}$

Red Light red White

The two light reds $\mathbf{Pr}_a$ and $\mathbf{Pr}_b$ are complementary for the production of a red and give 9 reds : 7 light reds in F_2. Again the two whites $\mathbf{Pr}_1$ and $\mathbf{Pr}_2$ are complementary for production of a light red colour and give in the F_2 9 light red: 7 white.

The red allele $\mathbf{Pr}_1$ of series 1 when crossed to a new race of white gave a red F_1 and 15 reds: 1 white in F_2 showing that this new white is a double recessive at the $\mathbf{Pr}_1$ and $\mathbf{Pr}_2$ loci. It further shows that the reds resulting from the complementary action of $\mathbf{Pr}_a$ and $\mathbf{Pr}_b$ and $\mathbf{Pr}_1$ and $\mathbf{Pr}_2$ respectively are genotypically different from the red allele of series 1.

(e) *Grey brown rice.* An interesting segregation for rice colour has been recorded by Parnell *et al.* [1922]. In a natural cross they obtained a segregation of 9 full red : 3 grey brown : 4 white. It was further observed in the segregating families that the red occurred in plants with purple pigmentation in its vegetative parts, its place being taken by grey brown in unpigmented plants, i.e. giving 3 pigmented red to 1 unpigmented grey brown. It was, therefore, suggested by them that only a single red gene **R** was concerned which was able to produce full colour only in the presence of the particular purple pigmentation gene that was segregating; in the absence of this pigmentation gene, the red rice gene gives a grey brown rice. The existence of unpigmented varieties with red rice would be explained on the assumption that they lack one of the two pigmentation genes **A** and **N** (**N** corresponds to **C** in the proposed new genic symbolisation) which are shown to be necessary for producing anthocyanin in the rice plant. Taking **A** as the segregating pigmentation gene which is connected with rice colour, **AR** will be red and **aR** grey brown.

The hypothesis was confirmed in a test cross between an unpigmented plant with grey brown rice (**aaNNRR**) and a pigmented plant with white rice (**AANNrr**). Another cross was made between the same unpigmented grey brown (**aaNNRR**) and an unpigmented white of the constitution **AANNrr.** As expected the F_1 was pigmented and had red rice because its constitution was **AaNnRr.** The F_2 segregation given below is in close agreement with the theoretical expectations.

	Pigmented			Unpigmented		
	Red ANR	White ANr	Red AnR	Grey brown aNR anR	White Anr aNr anr	
Observed ..	283	119	108	129	85	$\chi^2=5\cdot46$
Calculated 27 : 9 : 9 : 12 : 7 ..	305	102	102	136	79	P is between 0·2 and 0·3

Parnell *et al.* [*loc. cit*] recorded that a red riced plant from an F_2 family that was noted to be segregating, but whose phenotypes were not counted, gave in F_3 a ratio of 9 full red to 7 white; twentyfour segregating F_4 families however showed an extraordinary range of ratios varying from 9 : 3.3 to 9 : 5.9 but with a few approximating to 9 : 7 of red to white.

It would appear however that at least two genes were concerned. Further studies had shown that all progenies from a family giving approximately 3 : 1 ratios ranged round 3 : 1 in the next generation whereas, progenies from families giving a 9 : 7 ratio gave a wide range of ratios varying from 9 : 3.3 to 9.11. The authors suggested that it might be due to some linkage between red rice genes and some other genes which had not been studied.

From the results published by the Japanese workers it would appear that what they call reddish brown and yellowish correspond to red and grey brown, described by Parnell *et al.* in the earlier paragraphs. Nagai [1921] obtained a ratio of 9 reddish brown to 3 yellowish brown to 4 white, similar to that of Parnell *et al.* [*loc. cit.*] described before. Kato and Ishikawa [1921] recognised reddish brown and white to the either monogenically or digenically different from each other. Further an interesting cross has been reported by the same authors in which two varieties of white rice when crossed gave reddish brown in F_1 and three phenotypes in the ratio of 9 reddish brown : 3 yellow : 4 white in F_2. These results were explained on a trigenic basis **A, B** and **C, ABC** resulting in reddish brown, **ADc** in yellowish brown and others in white.

Mendiola [1920] has recorded that by natural crossing an ear-head with white rice gave two grains with pink kernels. One of them gave white in the F_1 and in F_2 gave only six per cent of plants with white kernel and 94 per cent with red. The author offered the explanation (1) that the abnormal behaviour was due to environment and (2) that there was possibly present in the original kernel an inhibitory factor which prevented the expression of red in F_1. The partial dominance of red in the second generation might be due to the presence of inhibitory determiner which prevented red from manifesting its total potency. This explanation is, however, complicated and the behaviour needs confirmation.

(f) *Purple rice × white rice.* Most of the purple rices seem to be glutinous in character; however there appears to be no genetic association between purple and glutinous endosperm. Parnell *et al.* [*loc. cit.*] obtained a monogenic difference between purple and white rice. In the purple rice parent the kernel is almost black but in the F_2 they obtained a large variation in colour, some with only traces of purple, the dark type corresponding to the parent never being realised. Though all grades of purple grouped together gave a 3 : 1 ratio or purple to no purple, the non-recovery of the dark type corresponding in intensity to the parent even in several thousands of plants examined could not be easily explained. It may be that the single gene responsible for purple should have a particular background on which only the depth of colour can show. Though the F_2 variation was practically continuous, in the F_3 generation the darker types bred true, the lighter types being mostly heterozygous. The authors suggested that there might be minor modifiers besides the main gene. Mitra *et al.* [*loc. cit.*] obtained a monogenic difference between purple (of shades) and white pericarp colour. The gene expressing the purple colour may be designated **Prp.**

(g) *Purple rice × red rice.* Parnell *et al.* [*loc. cit.*] working with a cross between purple and red rice obtained a purple-red F_1, showing segregation in the F_2 generation into purple : red : white in the ratio of 12 : 3 : 1. The purple also exhibited extreme variation; some pure purple showed considerable reduction in the purple colouration and in every case the **Prp Prp Pr Pr** appeared as purple reds. This involved genes **Prp** and **Pr**; the purple is either **Prp Pr** or **Prp pr**; red is **prp Pr**; and **prp Pr** *is white.* The purple rice character did not appear to be affected by the gene. Ih, as in the case of the red rice gene. Thus in one family segregating for **Ih** in the presence of **Prp** plants with golden lemma and palea (with **Ih**) as well as those with dark furrows (with factor **Ih**) showed the same purple rice colour.

(h) *Purple and brown rice.* Parnell *et al.* [*loc. cit.*] have shown that as the pigmentation gene **A** is necessary for the production of red rice so also it is necessary for the production of the purple, and in its absence the factor **Prp** produces brown rice. **A** natural cross which was discovered to be of the constitution **AaNnPrp prp Pr pr** was studied by them in F_2 and F_3 generations, but no actual counts were made as it was a matter of great difficulty to obtain reliable figures where a number of different types of rice colours were concerned. The F_2 gave a ratio of 9 pigmented to 7 nonpigmented plants as expected on the basis of segregation for two genes **A** and **N.** Sixty F_3 families gave types of segregation as expected in accordance with the above constitution.

Ramiah (unpublished records of the Paddy Breeding Station, Coimbatore) had studied the purple colour in a natural cross involving the two pigmentation genes **A** and **N** and the purple and red colour genes **Prp** and **Pr**. One variety T.1357 has no colour in any part of the plant except the rice which is dark purple. A natural cross was observed in this variety which had purple colour in various parts, internode, glume, stigma, etc. and had also purple-red rice. The F_2 was grown and it gave a ratio of 9 pigmented to 7 non-pigmented plants, this showed that the plant was heterozygous for the two purple basic genes **A** and **N.** Since for rice colour a segregation of 12 purple : 3 red : 1 white was obtained, the F_1 must have been heterozygous for purple and red rice genes. Thus the F_1 might be taken to be of the constitution **Aa Nn Prp prp Pr pr** and the F_2 segregation with regard to colour of rice in the purple plants will be :

9 **Prp pr** : 3 **Prp pr** : 3 **prp pr**, 1 **prp pr** : [i.e. 12 purple (including purplish red) : 3 red : 1 white.

The F_3 studies confirmed the F_2 results.

To confirm the theoretical constitution of purple and brown rices an unpigmented plant with brown rice (constitution **aaNNPrpPrp**) was crossed with a pigmented type with white rice (constitution **AANNprp prp** [Ramiah *et al.*, 1931]. The F_1 as expected was pigmented and had purple rice. The F_2 gave only four types of plants as shown below. The fit is not good but it shows clearly the type of segregation.

Frequencies of F_2 of pigmented, white rice × unpigmented brown rice

	Pigmented plants		Unpigmented plants		
	Purple rice	White rice	Brown rice	White rice	
Observed	309	123	142	53	Fit not good
Calculated 9 : 3 : 3 : 1 ..	351	117	117	39	

(i) *Red rice* × *golden rice.*—Parnell *et al.* [loc. cit.] have studied this pair of characters in a number of families which were also studied for the golden (reddish brown) and dark furrows of lemma and palea. It has already been recorded that the presence of gene **Ih** inhibits gold colouring in the lemma and palea and changes it to dark furrows; they found that in the golden lemma plants the **Pr** gene for red produces golden rice and in the presence of **Ih**, i.e. in dark furrows it produces dark red. The same applies to the various shades of light reddish rice which are generally met with only in dark furrow types. In types with gold lemma and palea it is replaced by a yellowish or creamy colour. This has been verified by crosses between a plant with dark furrows lemma and red rice and another with gold lemma and yellow rice. The F_1 and F_2 data confirmed the expectations.

Narasingarao (unpublished records) studying a cross between a plant with straw lemma, red rice and another with a gold lemma white rice obtained in the F_2 the following ratios :

	Straw-furrows lemma (Ih)		Gold lemma (ih)		$\chi^2=0\cdot85$
	Red rice Pr	White rice pr	Gold rice Pr	White rice pr	
Observed	163	73	63	20	P is between 0·9 and 0·8
Calculated 9 : 3 : 3 : 1 ..	180	60	60	20	

Thus the above hypothesis that **Pr** in the presence of **ih** gives gold rice is proved.

Terao [1921] in crosses between a brown rice and different white riced parents obtained in F_2 generation a ratio of 3 : 1 of brown to white and 9 : 3 : 4 of brown : yellowish brown : white. Making a number of test crosses he confirmed that three factors **A**, **B** and **C** were concerned in the production of brown pigment, **A B** alone resulting in yellow, the rest of the combinations being white. The white is supposed to be always homozygous for one factor, i.e. **B**. The ratios are more or less similar to the ratios of 9 red to 3 grey brown and 4 white obtained by Parnell and Nagai. It is probable that the brown of Terao corresponds to the 'red' of Parnell or reddish brown of Nagai.

Thus the factorial constitution of the several colours in rices in terms of the genes so far identified may be set down as follows :

Red rice	*AN Pr prp Ih* or *An Pr prp Ih*
Grey brown rice	*aN Pr prp Ih* or *an Pr prp Ih*
Gold rice	*An Pr prp ih* or *An Pr prp ih*
Purple rice	*AN pr Prp* or *An pr Prp*
Brown rice	*aN pr Prp* or *an pr Prp*
White rice	*AN pr prp* or *an pr prp*

(2) *Endosperm characters*

The endosperm in rice, as in most of the cereals, arises from a fusion nuclei involving a micropolar nucleus, an antipodal polar nucleus and one of the male nuclei which enters the embryosac through the pollen tube. In the young developing seed, the endosperm completely invests the embryo but later on it becomes eccentric by displacing the embryo to one side. The outermost layer of the endosperm of rice, called the aleurone layer, is made of cells which store reserve food material in the form of proteins in contrast to the remainder of the endosperm where the food is in the form of carbohydrates, usually starch, or dextrins in glutinous rices.

(a) *Characters of the aleurone layer.* No exhaustive studies have been made with regard to the character of the aleurone. Ramiah and Mudaliar [1939] have studied histologically the proteins in the rice grain and the development of aleurone layer from the time of fertilisation. There were indications to show that in an early maturing variety the aleurone layer developed earlier than in a late maturing one, and coloured rices have thicker aleurone layer than white rices, the maximum development being found in purple rice. The thickness of the aleurone showed an association with the size of the grain, the earlier maturing coarser rices generally having a thicker aleurone layer than the finer rices. Initial soil fertility differences as well as manuring have an influence on the thickness of the aleurone layer; in poor soils the aleurone layer is thin and the thickness is found to increase when the soil is manured either with fertilisers or green leaf, the increase being more in the latter case.

The aleurone layer in rice is not coloured unlike in the case of maize. It would appear that owing to the intractable nature of the rice grain for histological studies detailed investigations could not be made until recently. As aleurone is chiefly concerned in the nutrition of people whose diet is exclusively rice, its study promises to be a fruitful line and it is hoped more knowledge about its inheritance will also be gathered in the near future.

(b) *Texture—Hard and soft.* The endosperm in rice varies in texture according to the different amounts of soft and hard starch which it contains. In certain varieties, the middle part of the ventral side of the grain (side on which the embryo lies) there develops a white or chalky looking portion called the *abdominal white*. In most cases it exists along the edge of the ventral side and extends to a varying extent towards the centre of the grain. This character is generally to be found in coarse early maturing varieties. The grain with abdominal white has a low specific gravity and is more easily broken by pressure. It contains less albuminoids. This character has not received as much attention from the point of view of its heredity as it deserves. It is an important economic character as the high trade quality of a rice depends to a large extent on its absence.

The hard rices on the other hand appear more translucent and their cut surface looks more oily and less opaque than that of the soft grains. The correct determination whether a rice is hard or soft is still a matter of personal judgement of the investigator. But Codd *et al.* [1933] report that they have devised a machine to test the hardness of grain in British Guiana and it may be useful to describe this machine.

'It consists of a light beam 36 inches long and one inch square in cross section made of hard wood or some other fairly inflexible material. The beam is graduated in convenient units and is attached at one end to the top surface of a table, six inches from the edge with the beam projecting over the end of the table. On the under surface of the beam, about four inches from the point of attachment is a slightly projecting steel boss about half an inch in diameter which rests upon a steel plate sunk in the table. There is a slight groove in this plate passing underneath the boss. A scale pan is attached by means of a fishbone round the beam to a rolling pin which rests upon the beam. The rolling pin is fitted at one end with a disc. By turning this disc the distance of the scale pan from the point of attachment of the fulcrum can be varied. A rice grain is placed in the groove underneath the boss and known weight, say two pounds, is placed in the scale pan. The disc is turned away from the fulcrum until the grain is heard to crack when the reading is taken. A hundred whole grains are taken at random from a sample and tested this way and the mean determined. From the mean, the hardness of the rice is calculated as follows :

$$W = \frac{FX}{Y}$$ where W = hardness in lb. pressure.

F = weight in scale pan.

X = distance from the point at which W is applied to the fulcrum.

Y = distance from the steel boss to the fulcrum.

It has been found that hardness fluctuated inversely with the relative humidity. The maximum and minimum hardness so determined among the British Guiana rices were 17.8 and 12 lb. respectively.

The inheritance of this character was studied qualitatively in Coimbatore by Ramiah [1932] in a cross between 'hard' and 'soft' rice and the results roughly indicated a single gene difference though the ratios were not definite. Results of a cross studied by Jobithraj [1936] showed that 'soft' was incompletely dominant giving a ratio of 1 : 2 : 1 of soft : intermediate : hard in the F_2, the intermediate resembling more the soft than the hard. Of the one hundered and eighteen cultures studied in the F^{ε}, thirty progenies bred true to hardness thus confirming the hypothesis.

Grant [1938] studied a cross between plants with an opaque and translucent endosperm and got an F_1 which had some abdominal white. The F_2 gave a ratio of 1 translucent : 2 abdominal white : 1 opaque indicating probably a single gene difference. The F_3s and F_4 s however did not entirely confirm this finding. Evidently the character was not simple enough to judge qualitatively in a segregating family. The translucent and opaque characters may be designated O_p and o_p.

Dave [1939] reports xenia effect with regard to the texture of the endosperm. In a cross between a local strain (C.P.) with soft grain and the American *Blue rose* the grains on the main panicle of the F_1 showed a segregation of 3 : 1 of abdominal white to translucent endosperm. The abdominal white grains either bred true or segregated into abdominal white and translucent. The segregation of the panicles of 44 F_2 plants gave a good 3 : 1 of abdominal white to translucent showing thereby that abdominal white is dominant to translucent. While the above is in line with the results reported by Jobitharaj and others, it does not agree with Grant's results. It is possible that Grant was dealing with a different character. The presence and absence of abdominal white may be taken to be controlled by the allelomorphs **Wb—wb.**

(c) *Glutinous endosperm.* In certain varieties of rice the starch deposited in the endosperm is one of the lower forms of polysaccharides (probably dextrin). Though the rices are called glutinous rices, they do not contain real gluten. While the endosperm in the ordinary rices gives a blue reaction with iodine, the dextrinous endosperm in the glutinous rice gives a reddish brown colouration with iodine. It is not possible to cook the glutinous rices in the same way as ordinary rices, as the whole thing gets into a sticky mass.

The inheritance of the glutinous nature of the endosperm in contrast to the starchy has been studied by a number of workers, viz., Van der Stok, Kato, Ikeno and Hoshino [quoted by Matsura, 1933], Yamaguti [1918], Parnell *et al.* [1922], Takahashi [1923], Chao [1928, a], Ramiah *et al.* [1931] and Grant [1936]. All of them found the glutinous endosperm to be a simple recessive to the starchy. The effect of the foreign pollen called xenia could be seen in the endosperm quite clearly in a plant heterozygous for the character. Even in the flowers of the F_1 plants two kinds of pollen grains giving different reaction with iodine as in the case of the mature grain could be distinguished, Parnell [1921].

Almost all the investigators have generally found a deficiency in the recessive glutinous class and various explanations have been suggested by them. That it was not due to the irregularity of meiosis was proved by the fact that nearly equal numbers of viable pollen grains were produced for both the classes. Chao [1928, b] thinks that selective fertilisation or gametic incompatability is concerned in the irregular ratios. He suggested that the causes of deficiency might probably be due to differences in the development of male gametophyte and the differential pollen tube development; he thought that environmental factors might also influence the effect of glutinous gene on the rate of pollen tube development. Srinivasan [1941] however records that the pollen tube in the glutinous rice grew at the same rate as in the starchy rices. Yamaguti [1921] was of the opinion that a semi-lethal gene was associated with the glutinous gene. Backcrosses of the F with the recessive glutinous type were made at Coimbatore, Ramiah *et al.* [1931], and they obtained 125 plants resembling the F_1s and 95 glutinous. Though the deviation from the expected half and half of the two types does not exceed twice the standard error, the results do indicate the possibility of the glutinous pollen being weaker. They also conducted germination studies of the two kinds of grains obtained in the F_1 plant and realised a mean of 70 ± 2.7 per cent for the non-glutinous and 51 ± 2.3 for the glutinous showing clearly that there was a differential germination rate between the two kinds. It was also found that a good number of seedlings in the glutinous group were weak and it appeared doubtful whether they would reach maturity.

No association was found by Ramiah *et al.* [*loc. cit.*] to exist between endosperm and other characters but there was found a linkage between glutinous endosperm and one of the two anthocyanin pigment complementary genes responsible for colour in the axil and apiculus. Enomoto [1929] obtained from a glutinous variety a few non-glutinous plants which on selfing split into three non-glutinous to one glutinous. Though he explained this as a gene mutation from the recessive to the dominant, the possibility of their being natural crosses with a non-glutinous variety cannot be ruled out. The recessive gene which governs the glutinous endosperm may be designated as **wx** the common (starchy) condition being **wx.**

(d) *Scent*. Among the hundreds of varieties under cultivation in different parts of India there are a few known as scented rices forming a group by themselves. These scented rices emit a peculiar aroma, very similar to that associated with the flower of the tree, *Bassia longifolia*. The scent is highly esteemed by people in Northern India who cook the scented rice with meat. These are also called '*pulao*' rices. It is stated that the development of scent is dependent upon a number of environmental conditions. For example, the variety *Basmati* grown in the Dehradun district is said to be of a better quality than that grown elsewhere. It has been found, however, that the same *Basmati* rice grown in Bihar and Madras does retain its scent. A scheme has been sanctioned by the Indian Council of Agricultural Research recently to investigate the problems of quality of *pulao* rices in the Punjab.

It is not definitely known in what part of the grain the scent is concentrated nor to what active principle the scent is due. While the scent is invariably associated with the aroma that emanates while the rice is being cooked, it is possible to recognise it even when the empty husk is boiled in water and also by chewing a few grains in the mouth where the scent is strong enough. When the particular variety is in flower, the characteristic aroma can be detected even when one passes by it in the field, the scent being probably present in the dehiscing anthers also. Even the vegetative parts do sometimes give out the scent particularly in strongly scented rices.

Ramiah [1937, a] has shown that the character was inherited in a Mendelian fashion but owing to the difficulties in scoring he obtained in crosses between scented and nonscented varieties varying ratios of scented to nonscented. But some of them showed an approximation to a 3 : 1 of scented to nonscented indicating the recessive nature of nonscented group. In another cross he studied an approximate 9 : 7 ratio of scented to nonscented was also recorded. A general association between scent and the gene for red colour of rice was also detected in this latter cross as shown below :

Association of rice colour and scent

Scent	Rice colour				
	Various shades of purple and red	Various degrees of purple and white	Red	White	Total
Scented	85(72)	9(19)	26 (22)	1(8)	121
Non-scented	35(48)	22(12)	11(15)	12(5)	80

Previous work had shown that a cross between purple and red rice gave 12 purple : 3 red : 1 white rice. The expected ratios of scent on the basis of independence of the factors responsible for the scent are shown in brackets by the side of actual frequencies. Kadam and Patankar [1938] using the rice variety *sugdasi* as the scented parent, (which was also one of the parents in the cross giving a 15 : 1 ratio at Coimbatore mentioned later) studied the inheritance of scent in the progenies of crosses. The F_2 gave a ratio of 27 scented to 37 nonscented suggesting the interaction of three genes. Fifty F_3 progenies confirmed the F_2 results.

Dave [1940] studying crosses between scented and nonscented varieties realised a 3 : 1 of scented to nonscented the segregation being evident in the grains of the F panicles proving the effect of *xenia.* The scent was determined by him by breaking a rice grain under the teeth. Further work [Srinivasan, 1941] with crosses at Coimbatore between nonscented and scented varieties has shown that in one cross (T.24 × Rascadam) scent was dominant giving a 3 : 1 ratio of scented to non-scented and in another (*Sugdasi* × T.24) scent was governed by duplicate factors with a ratio of 15 : 1 of scented to nonscented.

The 27 : 37 ratio is governed by three cooperating genes $\mathbf{O_a}$, **a** $\mathbf{O_b}$ and O_c. A set of duplicate factors O_1 and O_2 is necessary to explain the 15 : 1 ratio. The 9 : 7 ratio means that two complementary genes are involved.

CHAPTER XIV

INHERITANCE OF PHYSIOLOGICAL AND QUANTITATIVE CHARACTERS

IN India until a decade ago the inheritance studies reported were those dealing mainly with obvious colour characters in several parts of the rice plant. It has been shown by later researches that the laws of inheritance were equally valid for more recondite quantitative and physiological characters; in fact genetics has a valuable contribution to make towards the elucidation of physiological problems. These include such characters as flowering duration, various kinds of sterility, resistance to pathogens, etc., and such quantitative characters as size and form of plant parts. There is an obvious interdependence between physiology and genetics. While yield, the most complex of characters, is determined by the physiological processes occurring during the course of development of the plant, the development is itself governed by the genetic constitution. To realise the full benefits of plant breeding, studies on the inheritance of quantitative characters would appear necessary. It is only since the last decade that attention has been paid to the genetics of quantitative and physiological characters and all the available information relating to such studies is dealt with in this chapter.

1. STERILITY

The problem of sterility in rice is very important, its presence in any form in a culture lessens the potential output of grain. Apart from the genetic basis, ordinary spikelet sterility in rice is considerably influenced by environment. Akemine and Hoshika [1939] studied the effects of environment on sterility by growing thirtytwo varieties of rice over a period of fourteen years. They found a high negative correlation between air temperature and percentage of sterility, the temperature one to twenty days before heading time, having a greater influence than the temperatures at other periods. Percentage of humidity higher than eightyfour increased the amount of sterility. Longer sunshine had a good effect in reducing sterility. Applying the partial correlation method, the authors found that the independent effect of sunshine and humidity was comparatively slight and that of air temperature was the deciding factor in the occurrence of sterility in the rice plant.

At Coimbatore, one of the environmental conditions that affected this character most was found to be the time at which flowering took place [Ramiah 1931]. Too much rain or too dry a condition of the soil at the time when plants transpired most, i.e. at and just before the flowering phase. are stated to result in a large amount of sterile spikelets. Rain must effect air temperature and it is possible that the low air temperature with high humidity were the primary causes for the sterility, as observed by the Japanese workers. High fertility of the soil which makes the crop lodge just at the time of flowering was also shown to result in a high percentage of unset spikelets. Alam [1936] has shown that the degree of sterility on the same plant varied a good deal from year to year and he believed that this variamility had no relation to the age of the plant or to weather conditions. Rainy weather in some cases had increased the sterility but no definite correlation between the two was found by him. There are several forms of sterility that are met with in rice. The most usual form of sterility is the failure to set grain of a certain number of intermediate spikelets in the panicle though they are perfect, containing both normal anthers and stigmas. Apart from the environmental factors which create physical disabilities at different stages for the successful formation of fruit, sterility results from a number of internal causes pertaining to cells, chromosomes and genes.

Spikelet sterility

Sterility characteristic of the culture, governed by specific genes, may be called 'spikelet sterility' to disinguish it from other forms of sterility to be described later. Examination of the floral parts would show that this sterility may be due to the uneven maturity of pollen and stigma, aborted pollen and non-functioning of the pollen even when well-formed. A few instances where defective stigma was the cause of sterility have also been noted [Ramiah *loc. cit.*]. The large amount of sterility occurring sometimes in crosses even amongst the same geographical group is a difficulty to be met with in breeding programmes though it may not be unsurmountable. In recent years attempts are being made at almost all the rice breeding stations in India to synthesize the good qualities found in different cultures by hybridisation, and in the study of the resulting progenies, the problem of sterility has received its share of attention.

Extensive studies were made at Coimbatore [Ramiah *loc. cit.*] with regard to sterility character in a number of crosses between pure lines. Some of the parents had almost no sterility at all but when they were crossed a small amount of sterility usually occurred in the F_1, but in the later generations, the degree of sterility varied and the variation was generally of a complex nature not analysable into any definite groups or ratios. Alam [*loc. cit.*] studying sterility in a number of pure lines of varieties has recorded that in those cultures which were segregating for sterility, there were smaller numbers in the high sterility classes thereby suggesting that sterility might be a recessive character. In crosses made between *Sathi* (having an enclosed ear type) with a number of pure lines which were widely different from *Sathi*, Sethi [1936] observed the percentage of sterility to vary from anywhere between ten to fifty per cent in the F_2 generations. No quantitative data was, however, gathered. While some cultures were uniformly very much sterile, in other cases the plants were more or less free except for a very small amount of sterility and some cultures possessed both types of plants. He found that sterile plants with more than sixty to eighty per cent of sterility bred pure for this character suggesting that sterility was probably recessive. Observations made on other material led the author to conclude that the character was possibly controlled by multiple genes and it was only by continued selection one would be able to reduce sterility to negligible proportions in later generations.

In connection with the attempts to improve the texture of rice in some trade varieties of Burma and Bengal, a number of crosses had been made between the indigenous types and such American rices as *Blue rose*, *Fortuna*, etc. Grant in Burma [1938] had made a critical study of the character in his crosses with *Blue rose*. With only a small percentage of sterility in F_1 it ranged from 1 to 87 per cent in F_2 and he thought that sterility and partial sterility were due to the interaction of several genes difficult to determine. He made a study of F_3 generation by selecting from the entire phenotypical range in F_2 plants. The study of a large population totalling to 10,726 plants in the F_3 generation showed that while the highly fertile and highly sterile groups yielded plants of similar fertility, the medium fertility group yielded plants varying from low to high fertility He also made a study of the pollen in the several fertility groups by classifying them into three groups, (1) poor pollen mostly empty, (2) irregularly round and (3) normal. It was found that most of the plants produced all the three classes of pollen in varying proportions and no relationship could be established between spikelet sterility and the type of pollen produced. Chakravarty and Banerjee in their crosses between American and local rices in Bengal obtained results very similar to those of Grant. There are indications that the type of sterility that has been dealt with is a recessive character and there may be more than one gene responsible for it. The basic symbol **f** may now be assigned which can be modified later when more definite information becomes available.

Sponginess

This is a form of sterility in which the spikelets at the tips of panicle branches or a few ones at the base remain rudimentary and undeveloped. They are white and papery in appearance, dry up and fall off later as the panicle ripens. Here both the anthers and the ovaries are aborted and this form of sterility, sometimes known as ‘sterile tips’ or ‘white sterility’ has been found to be a varietal character and is often associated with particular grain size and density of the panicle, and Ramiah [*loc. cit.*] found this to be a simple recessive. In the X-rayed material, Ramiah and Parthasarathy [1938] observed this type to occur as a mutation and it behaved as a simple recessive to the normal. It has also been found that environment affects this type of sterility, as for example, excessive manuring increases the incidence of the sterile tips in a culture which under ordinary conditions shows only a small incidence. Reyes *et al.* [1933] find that there is nearly a loss of 15 to 20 per cent in some Philippine rices due to the prevalence of this type of sterility. The gene controlling this character may be represented **fw** (white sterility).

Complete sterility

(a) *Paleaceous sterile.* Certain plants showing complete sterility arise as mutations both spontaneously and by applying external agencies as X-rays, etc. The appearance of such mutations is more frequent in hybrid material. Srinivasan [1938] obtained a plant which was completely sterile; it was short and had erect panicles and was called *stumpy sterile*, the inflorescence and spikelets resembled the multiple pistillate type.

Sugimoto [1923] obtained an abnormal plant in which the anthers were functionless and the ovary had no stigma and was empty. All these complete sterile forms were generally monogenic recessives to the normal. Nagai [1926] obtained a mutant in his work which he called paleaceous sterile which was functionless in both the sexes and which had either rolled or normal leaves. The gene governing this kind of sterility may be designated **fp**

(b) *Barren sterile.* This mutant was first discovered by Anandan and Krishnaswamy [1934] in one of the pure lines, *Muthu samba*. A special feature observed by the authors was the dimorphism for grain size in the plant heterozygous for the barren sterile character. Two classes of grain with mean lengths of 6.9 mm. and 7.5 mm. could be made out in the same panicle and it was noticed that grains below 7.3 mm. in length were heterozygous for the character and those above 7.3 mm. in length were pure for normal. The mutant had twice the number of tillers as the normal, the leaf blades were reduced in size and the plants were shorter than the normal which may all be pleiotropic effects of the single gene, which may be designated **fb**. Although the simple recessive nature of the mutant was indicated, the steriles were always less than one-fourth of the total population in the segregating families. The authors suggest that either the pollen carrying the mutant gene is not fully functional or there is a greater mortality in the sterile group. Cytological studies of this mutation have shown that it has only 22 chromosomes instead of 24, Sampath and Krishnasami [1948].

Another type of barren sterile, somewhat different from the above in that there was formation of boot leaf and flower primordia, was obtained by Ramiah [1936] in the X-rayed material of a pure line. The plant was characterised by lateness with thin and long flag leaf and small ear heads with reduced florets. In families segregating for this mutation a ratio of 15 normal to 1 barren sterile was obtained. Further generations have always given only two genotypes, one pure for normal and the other giving a 15 : 1 segregation. While it is definite that the mutant is controlled by a pair of duplicate recessive genes, the absence of families giving a 3 : 1 ratio of normal to barren sterile, is difficult to explain. The genes governing this barren sterile mutant may be designated **fb**$_1$ and **fb**$_2$.

(c) *Sterility due to asynapsis.* In the bulk crop of a pure line grown at Coimbatore, Ramanujam and Parthasarathy [1935] obtained a sterile plant where the flower opening was not normal and the anthers were considerably reduced and nondehiscent. The pollen was all aborted and the ovule sterility was also complete. Cytological examination showed there was lack of pairing of homologous chromosomes and a true reduction division was absent. It would seem that the non-pairing of chromosomes in this case was due to genic control. After repeated attempts the asynaptic mutant produced a few seeds when it was intercultured with normal plants. The F_1s were normal and the F_2 gave a ratio of 9 normal to 7 asynaptic plants, and the F_3 generation confined the F_2 results. This would indicate that the mutation has occurred in the zygotic cell and complementary genes were concerned in the inheritance of the asynaptic character which may be designated as **fas**$_1$ and **fas**$_2$. Similar asynaptic plants recorded in maize, tobacco and *datura* behave as a simple recessive to the normal.

Total male sterility

Ramanujam [1935] has recorded the occurrence of a sterile plant in the pure line Geb. 24, characterised by a protracted growing habit with non-emergent panicles bearing spikelets which failed to open. The spikelets contained considerably reduced and non-dehiscent anthers and the pollen when examined was all aborted. It however set ten fertile seeds by cross fertilisation with the neighbouring normal plants and the hybrids gave a

3 : 1 ratio of normal to sterile plants. Cytological examination of the pollen meiosis revealed no apparent irregularities at reduction division, but the spores degenerated following a fairly normal sporogenesis. A plant, with negative exsertion very similar to the male sterility described by Ramanujam, was obtained in the F_2 of a progeny of a cross which behaved as a simple recessive [Srinivasan *loc. cit.*]. Its absence in the F_2 Progeny would suggest that this character must have arisen by mutation in the F_1 hybrid. Sterility of this kind is termed 'male sterility' on analogy with a similar mutation in maize. It is definite that the sterility is genotypically controlled. The gene causing male sterility may be designated **fm.** Ishikawa [1929] and Miyazawa [1935] have recorded the occurrence of a similar mutation which on crossing with a normal pollen parent set some seed giving rise to 3 normal to 1 sterile indicating the simple recessive nature of male sterility.

Nagai [*loc. cit.*] recorded a mutant which he named *awned sterile* in which there was complete sterility of the male gametes. The plant had normal leaves and full awns and it was recessive to the normal. This is another gene causing male sterility and may be designated **fan.**

Female sterility

(a) *Staminoidal sterility.* Sterility where the defect is with the ovary though not so common in rice has been reported by a few workers. Nagai [*loc. cit.*] isolated a plant in which the female gametes were completely sterile characterised by the rolling of leaf at its base so that it developed downwards instead of remaining upright. This he called staminoidal sterile, and it was found to be a monogenic recessive to the normal. The gene which controls this sterility may be designated **fst**

Nagai had tried to explain the staminoidal sterile, awned sterile and paleaceous sterile with the rolled and normal leaved combinations on the presence of three sets of genes.

N-n-ń—a series of triple allelomorphs where **N** = normal ; **n** = staminoidal sterile ; ń = roll leaved sterile.

S-s—in the presence of **N,s** gives the awned sterile.

G-g—another pair of allelomorphs ; in the presence of **N** or **ń** gives paleaceous sterile.

It is possible that the several sterile mutants may form a multiple allelomorphic series but in the absence of studies with test crosses it is not possible to state with certainty their interrelationship.

(b) *Pistillate sterility.* Miyazawa [*loc. cit.*] has reported a mutation where the pistil had degenerated which he called pistillate sterility and he obtained a 3 : 1 ratio of normal to sterile in the F_2 generation when crossed to a normal plant. Female or pistillate sterility is due to a gene designated **ffs.**

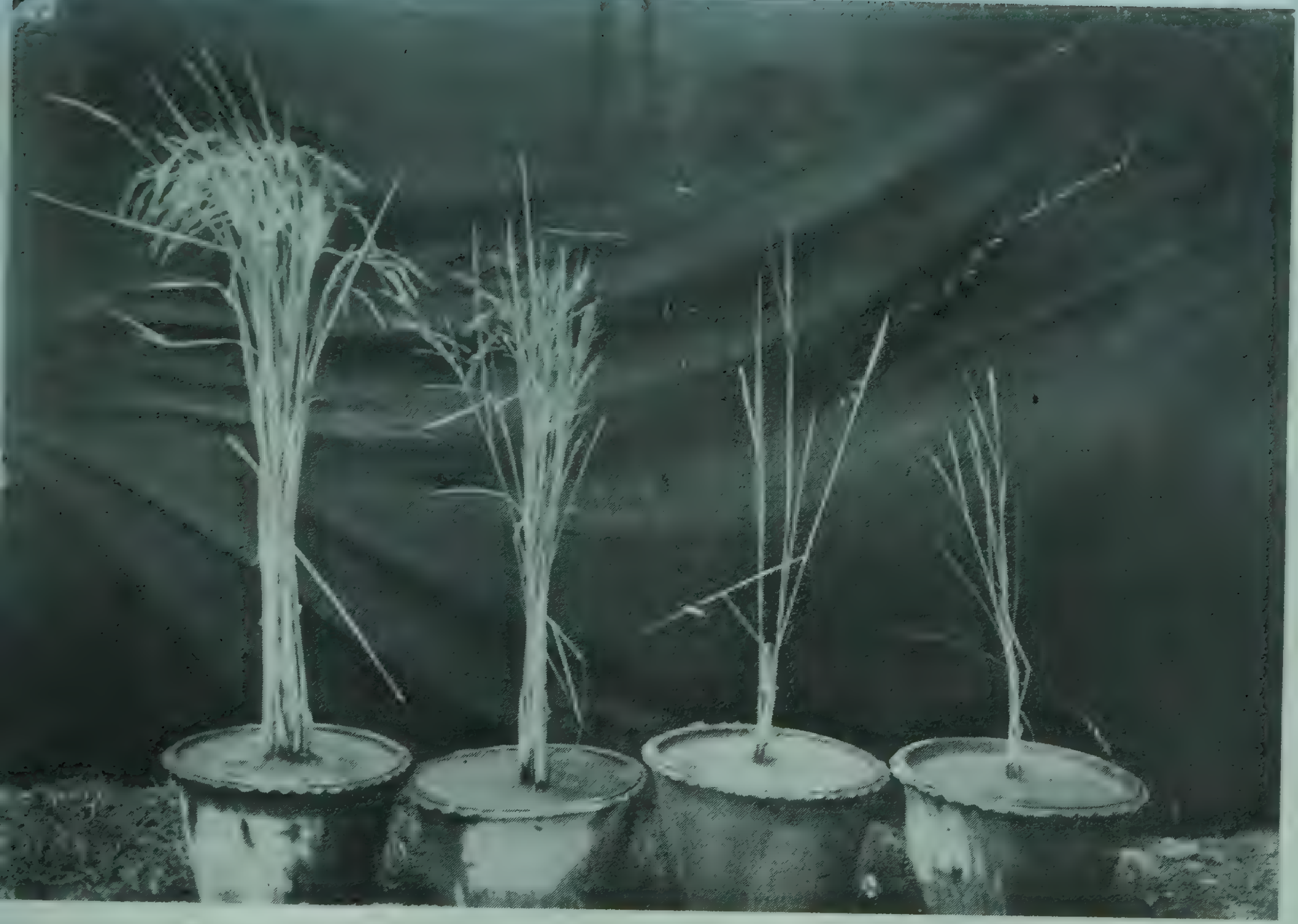
Semi-sterility

(a) *Spontaneous mutations.* Another form of sterility which may be called semi-sterility and almost similar to the spikelet sterility referred to already is more common in rice. The semi-sterile differs from the 'spikelet sterile' in that in spikelet sterility there is generally a gradation of sterility in the segregating families, whereas in semi-sterility the semi-sterile can be distinguished as a class and no continuous ' sterility ' groups are observable. In the case of semi-sterility the sexual organs may be morphologically perfect in all the spikelets ; semi-steriles occur mostly as mutations.

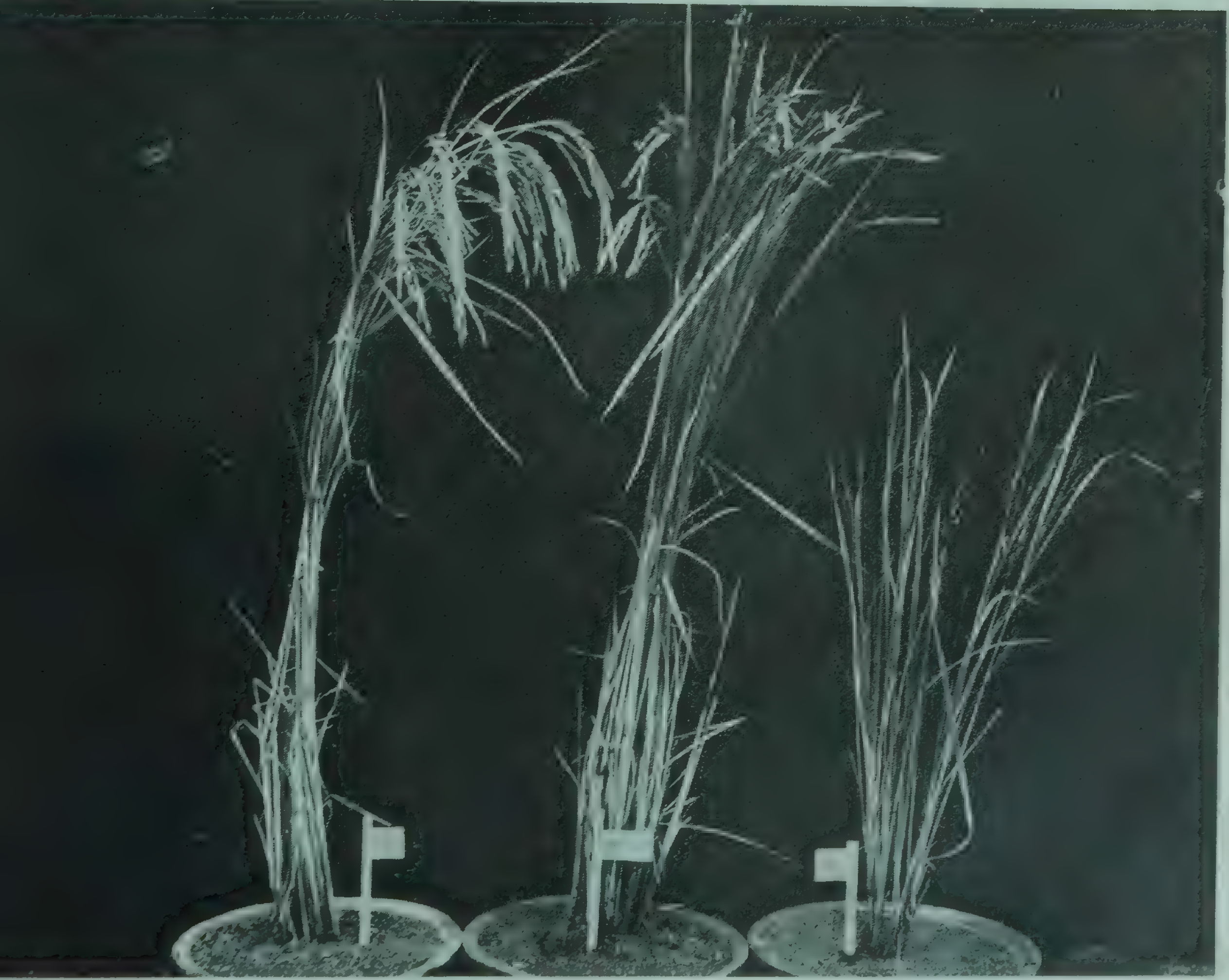
Many Japanese workers have studied the inheritance of different types of this sterility. Terao [1921] has reported of an ever segregating semi-sterile plant with a ratio of one fertile to one semi-sterile. He explained the semi-sterility as due to a sex-linked lethal gene **a** causing death of female gametes but not affecting the male its allelomorph **A** behaving normally. The zygote **Aa** produces **a** and **A** male gametes but only **A** female gametes and thus only two kinds of offspring in equal proportions result. The production of the semi-sterile was attributed to the mutation of allelomorph **A** in the original fertile zygote **AA** into **Aa.** This explanation may or may not be correct. It is possible that the results are due to a small deletion in the chromosomes.

Ishikawa [*loc. cit.*] obtained three kinds of ' steriles ', viz. (i) sterile (with 80 per cent sterility) similar to the male-sterile already referred to setting seed by pollination from normal pollen ; (ii) partially sterile (40 per cent sterile spikelets) which threw fertiles and partial fertiles in the ratio of 7 : 1 the fertiles always breeding true. Partial steriles were not obtained by intercrossing fertiles thrown by partial steriles and also when the partial sterile was fertilised by fertile. Thus the partial sterile is represented by **Ss.** On the female side only *S* gametes function. On the male side, **s** gametes can fertilise **S** eggs ; only a small part of **s** (1/7 **S**) fertilise **S** eggs on account of the presence probably of a lethal factor in the gamete ; (iii) semi-sterile, which was similar to the behaviour of the semi-sterile of Terao but the explanation offered was different. Ishikawa supposes that the semi-sterile is heterozygous for two genes **A** and **B** both double dominant and double recessive being abortive. Hence half the gametes of semi-sterile **Ab** and **aB** are only functional and the zygotes obtained are 1 **AAbb** 2 **AaBb** and 1 **aaBB.** The first and last are fertile and breed true, the semi-steriles again splitting. After liberation of tetrad pollen, abortion occurs in the semi-sterile ; **A** like **B** produces substances necessary for the development of gametes so that a gamete bearing neither of them naturally degenerates. A gamete bearing both of them also does not develop owing to some surplus substances produced by them. The hypothesis was borne out to be true by the observation that half the ovules and pollen were really abortive.

Kondo [1928] got a partial sterile as a mutant which behaved as a monogenic recessive to the normal. Among fertile plants in the F_2 generation the ratio of homozygotes to heterozygotes was 1 : 3.5 instead of 1 : 2 and among the offspring of the heterozygous fertiles the expected ratio of 3 : 1 of fertile to sterile was very often altered considerably. Sometimes the offspring of fertile plants were wholly fertile. This was explained by assuming a reverse mutation of the gene **F** $\rightleftarrows$ **f** where **F** causes fertility and **f** semi-fertility). Kagawa [1940] observed a semi-sterile having a thick stalk, bearded, loose panicles and large grains which bred true. This was different from the semi-sterile heterozygous plants mentioned before. The semi-sterile gene may be designated **fs.**



Normal Stumpy Beaked Narrow leaf



Normal Semi-sterile Dwarf

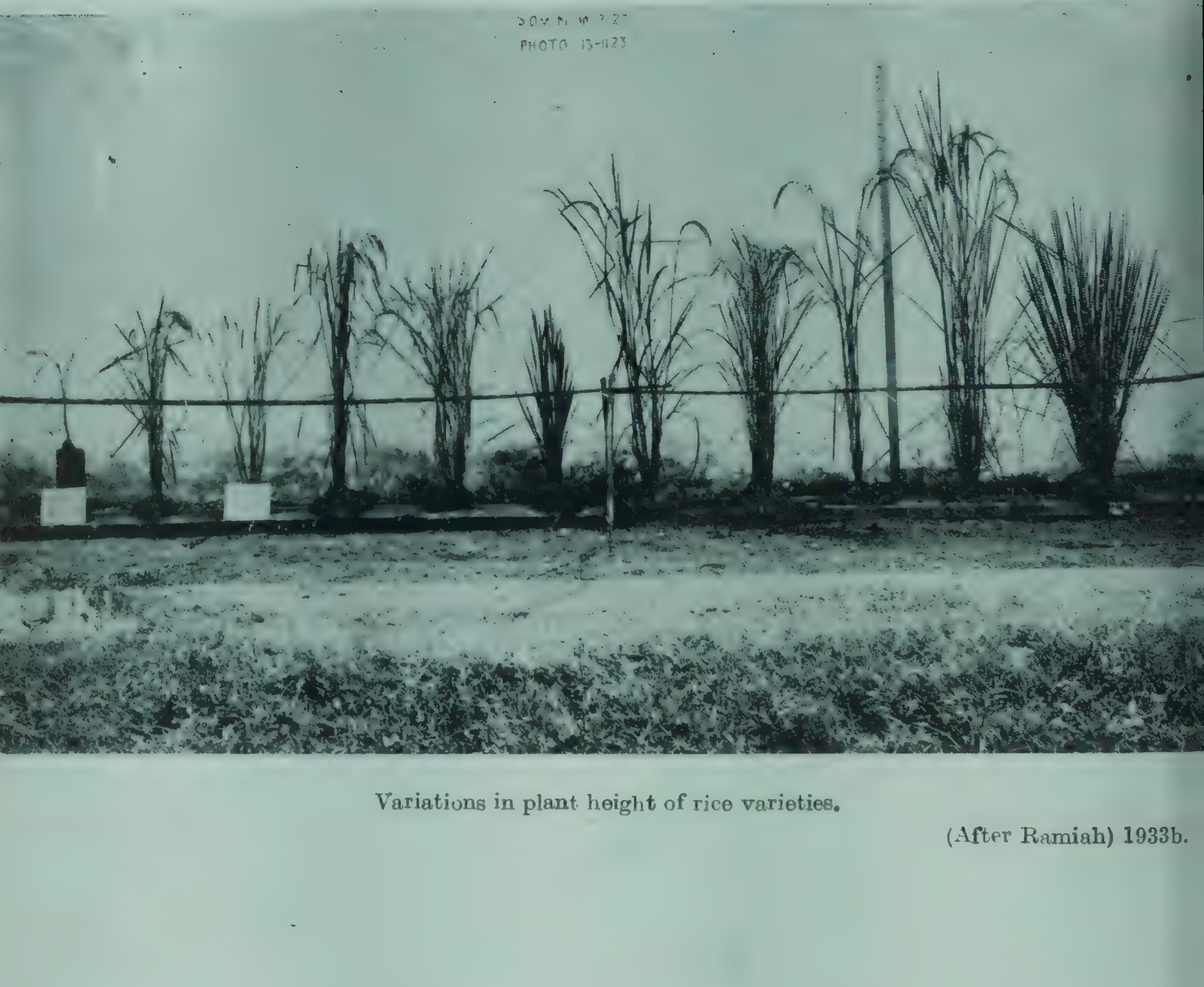


PHOTO 13-1123

Variations in plant height of rice varieties.

(After Ramiah) 1933b.

Miyazawa [1932] has reported two cases of semi-sterility in one of which the lemma and palea remain open after flowering and a few ripe grains are obtainable. Though no inheritance studies were made, this character was found to be transmitted to the offspring. In another mutation, similar externally to the above, the pistil had three stigmas, grains triangular and the palea generally small and slender. No inheritance studies have been reported about this mutation also.

Miyazawa [1935] studied the inheritance of various kinds of semi-steriles and reported their behaviour as follows : (1) Semi-sterile giving 1 : 1 of fertile to semi-steriles, the fertiles always breeding pure and semi-steriles repeating the behaviour. This is explained by factor mutation and lethal action of gametes. (2) Semi-sterile always more than half in each family (fertile : semi-sterile = 42 : 58). Pollen in the two groups does not show abnormalities. (3) Semisterility of varying percentages as obtained by Kondo. This is alleged to be due to reversible mutation of fertile to sterile and *vice versa*. (4) Semi-steriles always producing only fertiles. This could not be explained. (5) Semi-steriles breeding true which is due to simultaneous factor mutation of the double dominant fertile to double recessive fertile. (6) Semi-sterility was always associated with an abnormal character as 'slender' in lemma, stems, etc. giving a ratio of 3 normal fertile to 1 slender semi-sterile, without crossovers. This is explained by assuming two genes; gametes containing one of them are alive in both sexes but male gametes containing the other are totally killed while certain ovules are able to live. But it may be a case of close linkage between these two characters.

A number of semi-sterile mutations associated with other characters were also studied by the same author, but they are not referred to here and for more information about them his original papers may be referred to.

Kagawa [1939] reported a partially sterile mutant type with large grains found in a culture of upland rice variety and which he showed to be a simple recessive to the normal, the gene concerned frequently mutating back to the normal condition. A fertile plant with short grains and reduced plant height was obtained as a mutant from the large grained one and which was partially sterile.

(b) *X-ray mutations.* Amongst the mutations that were obtained by X-ray treatment in rice at Coimbatore, there were a number of semi-steriles (Plate XXIII) and these are described below :

(i) *Semi-sterile mutant.* In the X_2 generation, a semi-sterile mutant was obtained which was just like the normal plant in general features and could be identified only by examination of the pollen.

This semi-sterile mutant on growing gave 51 semi-sterile : 16 dwarfs : 37 normals. In the next generation while the normals bred true, all the semi-steriles segregated giving 1,002 semi-steriles ; 273 dwarfs : 667 normals. The dwarfs could not be bred as they were totally sterile. The ratio of semi-sterile to non-semi-sterile may be roughly taken to be 1 : 1 (100 : 940). Cytological examination of the sterile plant [Parthasarathy, 1938] showed an association of four chromosomes and ten bivalents and this was the characteristic of many of the cells examined though the configuration of the four chromosomes was of different types depending upon chiasmata formation. This quadrivalent formation was shown to be due to interchange of segments between non-homologous chromosomes. Parthasarathy discussing alternate possibilities for the origin of these dwarfs showed it was due to the presence of a few small fragments of chromosomes in addition to the normal complement in one of the cells of semi-sterile plant. The significant reduction in the number of dwarfs which represent only 14 per cent instead of 25 per cent was believed to be due to the pollen carrying the interchange might not compete equally with the pollen carrying normal chromosomes.

(ii) *Beaked sterile.* In another line in X_2 generation three mutants occurred which were shorter than the normal with beaked or curved lemma and palea and sterility up to 50 per cent. In the next generation they gave :

	Normal	Beaked
Observed	200	49
Expected 3 : 1	187	62

The beaked sterile did not breed true in the succeeding generation and appeared only in a smaller proportion than 1/3rd of the normal while the normals always bred true. Cytological examination of the mutant, [Parthasarathy *loc. cit.*] showed that it was a trisomic (with 2n + 1) of the primary type and no association of more than three chromosomes was met with.

(iii) *Stumpy.* This is another mutant observed also in X_2 line and is distinguished from the normal by its shorter stature, thicker and fewer culms with a close arrangement of spikelets in the panicles and sterility up to 25 per cent. When grown in the X_3 generation it gave 69 normal : 25 stumpy : 7 of a new type with long narrow grain. When examined cytologically, Parthasarathy [*loc. cit.*] found it to be again a trisomic and that of a secondary type. He has also explained how it is possible to get in the progeny of the original secondary trisomic mutant a new type of trisomic and has shown that the new type 'long narrow grain' must have been of this origin.

2. DURATION

The most important of the physiological characters of the rice plant is 'duration' or the period which it takes to complete its life cycle, from the germination of seed to the formation of seed grain. Amongst the several cultivated rices, there are varieties which have a duration of eighty days and others which take nearly eight months to complete their life cycle, with varieties of all intermediate periods between these two extremes.

Influence of environment on duration

For a transplanted rice crop the total period of growth may conveniently be divided into three portions, viz. (i) nursery period, (ii) the period of growth from transplanting to flowering and (iii) the ripening period, i.e. from the time of flowering to the full development of seed. All varieties of rice can be transplanted but it is the exigencies of climate and irrigation facilities that preclude this practice being universally adopted and have led to the practice of direct sowing in certain areas. The ripening period is similar for most of the varieties with an average of thirty days; early varieties have a somewhat shorter ripening period than long duration varieties, and varieties blooming during the monsoon period take a little longer time to ripen than those which bloom in winter or summer. Differences in the life periods of rice varieties are mostly due to differences in the second period of growth; any change in climate, season, soil, or cultural treatment brings about a change mainly in this phase. It is very rarely that a variety is found to have a constant duration under different conditions.

To facilitate understanding, the terms used by Ramiah [1933, a] have been adopted here.

Season and period bound habits

Before the inheritance of this important character is taken up it will be pertinent to refer to a few instances of the influence of external conditions on duration. The most important factor which affects the duration of most of the rice varieties is the season at which they are planted. Some varieties become either shorter or longer in duration when sown out of the normal season. Among rices two broad groups may be recognised based upon their reactions when sown at different dates: (i) those which are time-limited called ' period-bound ', i.e. varieties which, irrespective of when they are sown or transplanted take more or less the same period to come to harvest and (ii) those varieties which are a season-limited or ' season-bound ' come to harvest at a particular season of the year with slight variations irrespective of time of sowing. Most of the short duration varieties, four months and less coming under the classes of *aus* of Bengal and *kar* of Madras, belong to the first group and all the rest of medium and long duration ones belong to the second group. The other factors which influence flowering to a lesser degree and hence also the life period are the spacing given to the plants and the fertility of the soil.

Extensive studies have been in progress in the different rice stations of India to gather information as to whether the varieties the breeders were dealing with, were season or period-bound by noting their response to different times of planting. Mitra [1924] noted that in Assam, *aus* was period-bound and *sail* was season-bound. Ramiah [1933, a] has shown that in one of the medium duration varieties when planted all the twelve months, the flowering duration varied from 90 to 230 days according to the time of planting. Sethi *et al.* [1936, a] have recorded that flowering duration was more affected in short duration and transplanted rices than in late types, delayed planting resulting in precocious flowering. Chakravarty [1937] had studied the response of rice varieties belonging to *aman* and *aus* groups to different dates of sowing and found that in *aus* (short duration variety) excepting the November and December plantings, the varieties took more or less a definite period of time to flower and in *aman* with the exception of October and November plantings, the varieties flowered at about the same time, middle or late October. Russian workers have explained the different flowering durations resulting from alterations in sowing dates in terms of the phasic development theory. In the case of rice even small annual periodic variations in the length of day in the tropics are supposed to produce differing photoperiodic reactions.

Inheritance studies

The inheritance of flowering duration has been investigated extensively in a number of crosses between parents differing by a small period and between those differing widely. From an examination of the results from crosses studied at Coimbatore, Ramiah [*loc. cit.*] found that the inheritance of this character may be simple with a single gene difference, or complicated. Earliness is generally found to be dominant to lateness though in one case earliness was found to be recessive. He, however, found that the pure early types extracted from crosses possessed a higher mean duration than the early parent and the extracted late types possessed somewhat a lower mean duration than the late parent, thus showing evidence of *shift* for this character. In crosses where the F_2 and F_3 behaviour conformed to a simple dominance of early over late, the gene responsible for earliness may be symbolised as **Fl**.

The above results are in accord with the results of Hector [1922]. Chiapelli [1930], Grant [1936] and Jones [1933] have, however, recorded that lateness was a simple dominant to earliness in their crosses. Bhide [1926] had also obtained a ratio varying from 2.84—2.75 to 1 for late and early plants in the F_2 s of two crosses.

Several complicated cases of inheritance of duration are also reported by many workers in India and abroad. Bhide [1926] obtained cases in which dominance of lateness was not evident, the F_2 curves being nearly normal and he assumed in such cases that duration was governed by multiple genes. Ramiah [*loc. cit.*] studied crosses between parents differing in duration and also between parents with similar duration. In one cross, (T.310 × Geb. 24). where the parents had a mean flowering duration of 85 and 100 days respectively with their ranges just meeting each other, the F_1 resembled the early parent and the F_2 covered the range of both the parents. The F_3s were not studied individually for flowering duration but two of the F_4 selections gave a sharp segregation of 3 early to 1 late. Pure breeding extracted early and late types from the above were found to have mean flowering durations of 99 and 118 days respectively, the early extracted type corresponding to the original late parent in duration and the extracted late type being much later in duration than the late parent. These facts were explained with the help of two genes $\mathbf{E_2}$ and $\mathbf{E_3}$ with cumulative effect controlling earliness, one of these genes being present in each of the parent.

In another cross studied by Ramiah [*loc. cit.*] the two parents were both nearly of the same duration (96 days) and the F_1 (89 days) was earlier than the parents. In the F_2 there was transgressive variation on either side, the distribtuion approaching a normal curve indicating the existence of multiple genes. The parents though of the same duration must be constitutionally different for genes controlling duration. Pure types with average durations exceeding those of the parents have been extracted in later generations from this cross.

Two more crosses involving a common parent and two other early varieties were studied only in their F_3 and later generations as they were originally not intended for the study of this character. Some F_3 families showed a segregation of 3 early : 1 late in one cross and 1 early : 3 late in the second cross, the reverse of the above. These results he explained on the basis of an inhibitory gene which distinguished the two earlies, and this was confirmed by a test cross between the two earlies which produced 13 : 3 of early to late in F .

Another complicated case of inheritance of flowering duration is afforded by a third cross studied by the same author [Ramiah, *loc. cit.*] Here the parents differed in duration by about five weeks, the early parent being Geb. 24 with a mean duration of 102 days and the late type, T.280 with a mean flowering duration of 135 days. This latter type obtained originally from Java belongs to the group *O. sativa* forma *japonica.* The F_1 was intermediate and the F_2 progeny started flowering two weeks earlier than the early parent with a heavy flush corresponding to the flowering duration of the early parent and from then, there was a gradual fall in the flowering frequency till the thirteenth week. Beyond this date there was no regular flowering and some plants did not flower at all. Grouping the plants which finished their flowering by the thirteenth week into one class and the rest into another he obtained a good 15 : 1 ratio of early : late. The actual frequencies were :

	Early	Late
Observed	10,549	669
Expected 15 : 1	10,157	701

He carried the study to F_3 stage and tried to explain the results on a trigenic basis assuming differential effect for the three genes.

In a few other crosses, the F_1 was intermediate in duration between the two parents inclining more towards the early parent while in the F_2 there was no apparent segregation ; but in no case, however, did the range exceed the mean of the late parent. In one cross. out of 1157 F_3 families studied, 19 were found to be somewhat resembling the early parent in their range while there was none with a range corresponding to that of the late parent. This is analogous to the results obtained by Emerson and East in maize. Although the 19 families similar to the early parent out of 1157 F_2 plants would very roughly correspond to a trihybrid ratio (1 in 64) the fact that not a single type corresponding to the late parent was realised probably indicates that the number of genes concerned may even be more than three.

Sethi *et al.* [1936, b] observed that in one set of cross the F_2 distribution covered the parental extremes and could be divided into two distinct groups, a late and early one. in the ratio of 3 : 1 showing the dominance of lateness. The segregation in the F_3 confirmed the observation made in F_2. The correlation between the flowering duration of F_2 and F_3 families was very high and positive. They however observed that the lates were not all genotypically the same which was not consistent with the single gene hypothesis. They tried to explain the results on a trigenic basis but the assumptions were rather involved.

In a second cross the same authors [1938] observed that the frequency distribution of the F_2 was continuous and extended from the lower extreme of the early parent to well beyond the upper extreme of the late parent.

The F_2 durations tended to be reproduced in F_3 but the flofering duration of the families did not exhibit any relation to the corresponding F_2 values. There was a rapid increase in homozygosity and in F_6, several hybrid cultures, pure for different flowering durations were obtained. The inheritance they thought was obviously governed by several genes, though the actual number might not be many.

Nandi and Ganguli [1941] reported results of several crosses among summer (*boro*), autumn (*aus*) and winter (*aman*) rices. In a cross between early summer and winter rice, with durations of 69 and 134 days respectively, the F_1 was intermediate (106 days) and the F_2 gave a 3 : 1 ratio of early to late plants reckoned on either side of a minimum frequency class which was present. There were no plants earlier than the early parent but amongst the lates there were plants later than the late parent. The existence of three genes was assumed to explain the data.

In another early summer and autumn rice cross studied by the same authors the F_1 was intermediate, more leaning to the late parent and the F_2 progenies gave a normal curve; the early plants were only as early as the early parent while the late plants were later than the late parent, the transgressive segregation being definitely one-sided. There was a break and the frequencies on either side gave an approximate ratio of 1 : 3 of early to late. Most of the early cultures bred true in F_3. The cross between an autumn and winter rice gave a segregation transgressive on either side and gave two groups in the ratio of 3 late to 1 early.

In a cross between a late summer and a winter rice the F_1 was intermediate while the F_2 showed a wide range of variation with transgressive segregation on either side of the curve. From the data it would appear that the inheritance could be explained on a digenic hypothesis as was done by Ramiah [loc. cit.]

An interesting type of segregation has been reported from Bengal, Chakravarty [loc. cit.]. The segregation appeared to be mainly influenced by environment. The cross was between a short duration *aus* variety (period-fixed) flowering by about the 15th September and a long duration *aman* variety flowering towards the end of October. The F_1 was intermediate and the F_2 was grown on different dates, once in each of the three situations differing in levels and consequently in moisture content and water availability. The first sowing was done broadcast on the 15th May and the second and third sets were transplanted by the 20th and 31st July respectively. In the first sowing (May 15), the segregation of flowering duration of the F_2 progeny was well marked with two distinct groups of 3 late to 1 early but in the other two cases the progeny was intermediate in duration and the curves were more or less normal covering the combined ranges of the two parents.

Srinivasan [1937], studied the inheritance of season and period-bound habit of flowering in crosses between three short duration 'period-fixed' varieties with a mean flowering duration of sixty to seventy days and another long duration season-fixed variety flowering normally in December-January when planted in July. The F_1 was sown and planted out of season, i.e. in December-January when only the true nature of flowering duration could be studied. The F_1 flowered towards the end of February indicating that the period-bound character is dominant to the season-bound nature. The F. was again grown in December and the nature of segregation confirmed the simple dominant nature of the season-bound habit.

In the crosses studied by Grant [1936] and Alam [1939] the segregation in F_2 generation was transgressive and the frequencies gave normal curves suggesting polygenic type of inheritance.

Jones [1928 and 1933] working with *japonica* rices has reported that the factorial situation for this character varied with the varieties used. The F_1 was either earlier than the early parent, later than the late parent or nearer the early or the late parent. In F_2 there was transgressive variation and trimodal frequency polygon with a small early group, a large intermediate group and a small late group was obtained; by grouping the frequencies, a 3 : 1 ratio of late to early was indicated. However the nature of transgressive variation observed in F_2 and F_3 generations and the realisation of different types of segregation between early and late in F_3 would appear to indicate the existence of more than one gene.

Inheritance of flowering duration has also been extensively studied in Japan. Hoshino [1915] found in a cross that F_2 segregation was complex with the combined ranges of the parents but no transgressive segregation occurred. The F_3 behaviour suggested that three genes were involved. Miyazawa [1916] and Ikeno [1926] both quoted by Matsura [1933] have suggested a polygenic scheme to explain their results. Nomura and Yamazaki [1927] quoted by Matsura [1933] studied a cross between an early and a late shooting race of rice. The F_1 was later than the late parent and in the F though there were two distinct groups in a ratio 3 late to 1 early, the early and the late plants of each group were somewhat earlier and later than the respective parents. The authors have explained the results on a trigenic basis, postulating at the same time differential quantitative effects for the three genes. Yamaguti [1927, b] inferred that three genes participated in determining the shooting time of F_2 and F_3 generations in a cross which he stated was however affected by season and cultural operations. Normally the effect of environment in F_2 is three times as great as that in F and there was found a strong correlation between the shooting time of F_2 parent and mean of F_3 progeny $(r = +0.823 \pm .038)$.

Thus a review of the entire body of evidence would show that the inheritance of this important character may be quite simple in some cases showing a single gene difference between earliness and lateness and rather complicated in others involving the interaction of two or more genes. Two varieties having identical flowering durations may still be different genotypically. The identity of the particular genes involved in the several crosses dealt with can be satisfactorily made out only by making an extensive collection of all the types used, at one place and making test crosses. Even where the inheritance was explainable on a single gene difference, it was possible to extract pure types differing in duration from the parent. The transgressive variation in certain crosses would, however, indicate the possibilities of obtaining by breeding extra early or extra late types. While the possibility of breeding specially early types does exist, it has to be ascertained how far such extra earliness can be combined with satisfactory yield. While there is no correlation between yield and duration, extremely early types, say, less than 100 days, are usually poor in yield. As regards earliness and lateness, earliness is generally found to be dominant and only very few cases where earliness was recessive have occurred in India. Under tropical conditions where earliness is a desirable character to suit the varying needs, selection must have gone on for a long time for this character. Fisher's Natural Selection and Theory of Dominance might explain the results where earliness is generally dominant. In the sub-tropical regions there is probably no point in selecting specially for earliness. This might account for the absence of dominance for this character in the crosses studied in Japan and America.

3. HEIGHT

Stature, being the external manifestation of vigour is an important character of plants. A moderate growth in height consistent with good fruiting is desirable. Amongst cereals too great a height which results in lodging at an early stage of the crop is a disadvantage. Too short a growth with even a good yield of grain is not generally preferred by the Indian cultivators, who value the straw as fodder for their livestock. Thus an optimum height resulting in a fair harvest of grain and straw is desirable. That a great variation in the mean heights of the several rice varieties exists, can be seen from the range of 66 to 142 cm. that has been found in the pure lines collected and studied at Coimbatore (Plate XXIV). Similar variations have also been observed by other workers in their collections.

Generally there is little difference in height among varieties in the early stages. The early varieties, however, start growth faster than the late ones and attain their full height in a shorter period. In the late ones, on the other hand, the growth is continuous though slow in the beginning and gets more rapid as the plants advance in age. Being a quantitative character studies on height inheritance have not been extensive. Though height is subject to a great variation due to environmental conditions, the error from this source can be reduced considerably by growing the parents along with the progenies every season.

Parnell *et al.* [1922] studied a cross between a dwarf variety and a tall one, and this has already been dealt with separately under dwarfism, as the parent showed a characteristic association of many characters with the height, and appeared to be different from other cases of stature inheritance. Ramiah [1933, b] has studied height, its inheritance and its association with several other characters, morphological and quantitative. In a few cases he obtained a definite bimodal curve in the F_2 with a break or a minimum frequency point, and the frequencies on either side of this point gave 3 : 1 of tall to short, showing the dominant nature of tallness. In one cross where also tallness was a simple dominant to shortness the extracted pure breeding 'talls' and 'shorts' had mean heights varying beyond the parental means and this he attributed to the presence of minor genes for height besides the main gene corresponding to the case discussed under duration inheritance.

Ikeno [1919] records that the F_1 of a cross between two rices generally approached the taller plant in height, and in one case, the height of the F_1

was intermediate between the two parents giving in F_2 tall, medium and short plants in the ratio of 1 : 2 : 1. He believed, that in general, the inheritance of height in rice did not appear simple. Ramiah in one of the crosses studied by him found tallness was dominant in F_1 but the F_2 frequencies gave a normal curve without any break with a transgressive variation. Similar results have been obtained by Grant [1935] in Burma. Studies of crosses in Assam by Nandi and Ganguli [1941] have shown that only in one case shortness was dominant and in the rest of the cases, tallness was dominant. Curiously Ramiah [*loc. cit.*] also obtained shortness behaving as dominant to tallness in one cross. Two parents with mean heights of 43 and 37 inches respectively gave in F_4 generation some progenies with a segregation of 3 : 1 of short to tall and one progeny showed transgressive variation on the tall side with a range of 36 to 56 inches. From out of the segregating families a 'short' and a 'tall' with mean heights of 42 and 52 inches respectively were extracted; the former corresponding to the mean height of the original tall parent and the latter, a new type much taller than the same tall parent. This he explained by assuming two genes $\mathbf{H}_1$ and $\mathbf{H}_2$ with cumulative effect controlling height, one of them being contributed by each of the parents.

Two more interesting sets of crosses have been reported by the same author; in these two crosses, one parent T. 102 was common, the other two parents being T.29 and T.6. In two families of the first cross, T.29 × T.102, in the F_3 generation which were segregating for height as well as for duration, the range of height started below the mean height of the short parent and went beyond the maximum range of the tall parent. They exhibited a clear minimum frequency point with a 3 : 1 ratio of short to tall. The mean height of the pure shorts varied from 44.5 to 50.5 inches and that of pure talls from 57 to 63 inches. The heterozygous shorts had a mean height of about 50 inches. Evidently the different shorts and talls were different genotypically. The other cross T.6 × T.102 had also proved interesting from the point of view of height inheritance. Some of the F_3 families exhibited a definite segregation for shorts and talls. In all the segregating families the height frequencies when plotted exhibited a definite break in the middle, the total shorts to total talls being in the ratio of 1 : 3, just the converse of the previous cross, as was obtained in the case of inheritance of flowering duration. Ramiah has explained the results of these crosses assuming the presence of three genes $\mathbf{H}_1$, $\mathbf{H}_2$, and $\mathbf{H}_3$ controlling heights, each gene having differential effects. Under the new gene symbolisation the height genes will be represented by $\mathbf{T}$, $\mathbf{T}_2$, etc.

In the inheritance studies height has been observed to be associated with a number of other characters. In some of the crosses studied by Ramiah he found that shortness went with earliness and tallness with longer duration. That this association is in all probability genetic in nature, i.e. the two characters are determined by separate genes but remain strongly linked gains support from the fact that in other crosses such association was not in evidence although there was segregation for duration. Another interesting observation that has been made is that in pure lines of long duration rices the correlation between height and flowering duration is generally negative while the same correlation is positive in the case of short duration rices. This observation of Ramiah partly confirms the results recorded by Srinivasan [1928].

It is probably reasonable to expect such a relationship. In an early variety the plants have to rush through their development and naturally, the ones that flower first could not have enough time to reach their maximum height and hence must be shorter in stature. In a long duration variety, however, there is a sufficiently long period for the plants to finish their development and those that flower early should be the most vigorous and show the maximum height. This explanation also fits in with the observations recorded at Maruteru that in long duration rices heavy yielding strains are generally obtained from the more vigorous, taller and early flowering plants.

It may be noted in passing that plant height has shown a positive correlation with such quantitative characters as ear-exsertion, length of ear, and yield. Among the morphological characters which have shown partial association with plant height are golden colour of lemma and palea and red colour of rice kernel.

4. TILLERING

The developmental phase of tillering has already been referred to earlier in the publication. It has been recognised that of all yield attributes, tillering is subject to a considerable variation due to changes in environment. The results of tillering studies can be of real value only when they come out of proper replicated trials, and even then, the results can at best be only comparative and cannot be taken as absolute values. But this apart, there is no doubt that tillering is a varietal characteristic governed by 'genes'. Owing to its being specially subject to such environmental influences as manuring and spacing, rice workers have not attempted to make any serious analysis of its quantitative nature though a large amount of data have been accumulated. The data, however, lack precision. The values of F_2 and F_3 generations represent the combined effects of environment and genetic constitution, and there is no way of separating them in the data available. It is only by supposing that the environment has had a uniform action on all the plants that the data of the several tillering studies can be analysed.

Ehide [1926] obtained in the F_2 generation of a cross between two rices differing in mean tiller values, a normal curve for the tillering frequencies and the coefficient of variation was higher than in the parents. He considered that the inheritance of tillering was controlled by multiple genes.

In a number of crosses studied at Coimbatore between pure lines which differed in their mean tillering values, tiller counts were recorded for F_2s and F_3s (unpublished records) and some of these are detailed below :

T.458 × T.63. The parents had a mean tiller value of 4.1 and 14.3 respectively and the F_1 was intermediate. The F_2 frequencies varied from 3 to 21 tillers in a long drawn out range with a definite skew on the left side. The F_3 was less variable than the F_2, and the coefficient of correlation between the F_2 plant value and F_3 progeny means was + 0.61 and highly significant. These facts indicate that the inheritance of this character was of the polygenic type, and the number of genes involved were not many.

T.381 × T.24. The mean number of tillers for the parents were 1.5 and 14 and the F_1 was again intermediate. In the F_2 the range was from 3 to 29 with a higher coefficient of variability than in either of the parents. In the F_3 generation, grown *in toto* the range of distribution of tiller means of the progenies was considerably reduced as compared to F_2. The long drawn out range in the F_2 generation should be mostly due to environmental causes. There were a good number of families in the F_3 generation with minimum variation in tillering amongst its plants probably indicating their homozygosity for one or more genes. The number of genes involved in this cross did not again appear to be large, probably not more than three or four.

T.332 × T.378. The tiller means of the parents were 3.9 and 13.8 respectively. Tillering was intermediate in F_1 and in the F_2 the range varied from one to twenty-six with a mean of 8.36. Two hundred and fourteen F_3 families had tiller means ranging from 3 to 11 and the coefficient of correlation between F_2 parental values and F_3 progeny means was + 0.184, suggesting only a week correlation. It would, therefore, appear that most of these F_3 families were still heterozygous and the number of genes involved must be larger in this cross than in the previous two.

Grant [1936] in his studies in Burma generally obtained an F_1, intermediate between the parents, and an F_2 with a continuous range of frequencies which could not be grouped and the segregation was generally transgressive. The results were very similar to the last of the three crosses mentioned above.

5. LODGING OF STRAW

In cereals one form of loss attaining considerable proportions in certain seasons is due to lodging or laying down of the crop, and rice is no exception to this phenomenon. It renders otherwise excellent varieties unsuitable for cultivation on certain soils. In a broad way, lodging may result from two sets of factors : (i) the interaction of those hereditary and environmental factors which contribute to the development of weak stems and (ii) purely external causes, such as mechanical impact caused by violent wind, storm, etc. These latter are generally accidental and beyond control. It is the first set of conditions that merits study which would be helpful to lessen lodging by suitable cultural modifications and in selecting strains with non-lodging character. Lodging is commonly believed to affect the migration of nutrients from the straw to the grain and thus a direct effect of lodging is to reduce the individual weight of grains formed. The amount of damage done to the crop varies with the stage of the plant at which 'lodging' takes place. The maximum loss occurs when the crop lodges just before it is in flower or immediately after it ; at other periods the crop does not suffer so much. When the crop lodges early in its life history, it has to regain an erect habit by 'kneeing' or bending at the nodes, different varieties exhibiting different capacity with regard to this character. In rice the nature of lodging has also been found to vary considerably [Ramiah and Mudaliar. 1934]. According to Marcarelli quoted by Copeland [1924], cold weather at the time when tillering should be active checks root development and later results in lodging. Mendiola [1926], believes that variability in wind exposure and depths of water during growing period influences lodging. The available literature on lodging, deals with the several aspects of the problem such as : (i) environmental conditions that influence lodving ; (ii) morphological and anatomical differences between lodged and non-lodged plants which might serve as an index in determining lodging ; (iii) mechanical determinations such as the diameter and strengths of straw ; (iv) chemical analyses of stem tissue, consisting of the estimation of nitrogen, carbo-

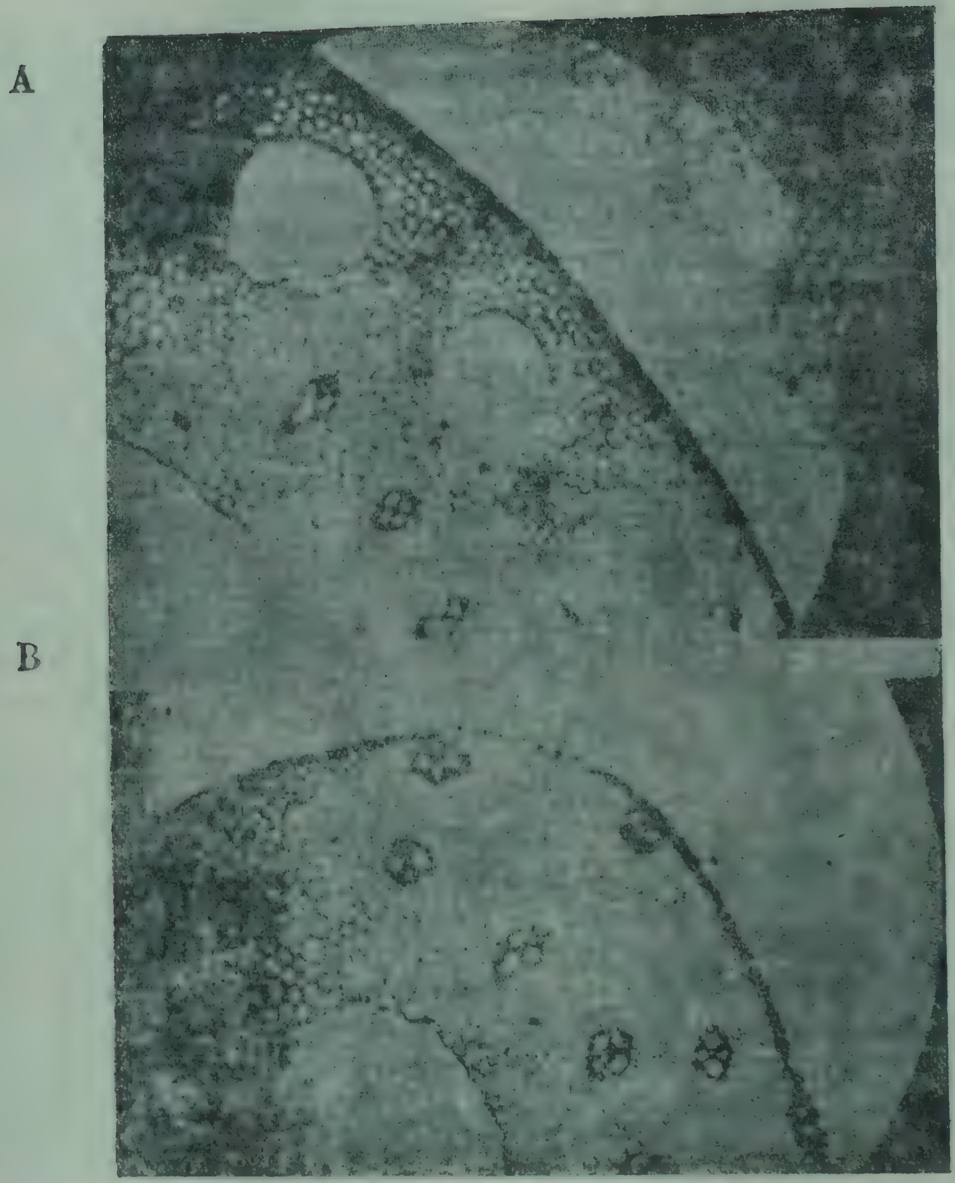


Fig. 4. Section of weak and stiff straw

A. Transverse section of a standing strain. Note the small celled, thick-walled cell (sclerenchyma) behind the air cavities.

B. Transverse section of a non-standing strain, showing the absence of sclerenchyma.

(After Bhide and Bhalerao, 1927).

hydrates, etc. (v) modifications of cultural practices to minimise losses and (vi) varietal adaptations. With regard to wheat, Engledow [1933] has said that 'in so far as lodging is related to the length of straw it is being attacked with some success but much has yet to be found out about its causes. The many investigations of stem anatomy have proved of little value. What seems to be needed is the study of the dynamics of the field plant'. The same applies to rice also.

In typically lodged and erect rice types growing in the field, Ramiah and Mudaliar [*loc. cit.*] have made a series of observations on morphological characters such as length and number of internodes above and below ground level, panicle length and weight, straw girth, total weight of plant, etc. and also on anatomical characters such as thickness of the culm and epidermis, number of vascular bundles, etc. No definite or clear relationship of these characters to lodging could be established but from the observed facts, however, certain broad conclusions were drawn by them which are mentioned below :

(a) The lodging varieties have a thin or decaying leaf sheath at or near the water level whereas, the erect varieties more frequently have strong and persistent leaf sheaths which may completely shroud the lower internodes and act as an effective support. This observation has been confirmed by Alam [1935] in rice varieties of Bihar.

(b) The diameter of the internodes, particularly those just above ground level (which are the ones concerned in lodging) is definitely greater, with and without the leaf sheath, in non-lodging than in lodging varieties.

(c) The thickness of the culm wall particularly the sclerenchyma portion is more in erect varieties, and this confirms the observations of Bhide and Bhalerao [1927] ; the parenchyma portion between the outer row of vascular bundles and the hollow centre is definitely broader in the erect than in the lodged varieties, Fig. 4.

(d) Certain non-lodging varieties have fewer layers of small sized sclerenchymatous cells behind the air cavities and connecting the fibrovascular bundles lying on either side of the air cavities which again confirms the findings of Bhide and Bhalerao [*loc. cit.*].

(e) Detailed measurements of internodes, heights of the lodged and non-lodged plants showed that lodging was brought about by too rapid a growth in the initial stages resulting in comparatively long internodes [Srinivasan and Ramiah, 1933]. In 'topping' of plants (removal of the top foliage) to prevent lodging, it was found that the length of the lower internodes got reduced and this gave more stability to the plant [Srinivasan 1930].

Lodging is essentially a problem of fertile lands. Those agronomic conditions which produce big yields, viz. good cultivation, initial high fertility, early planting and application of fertilizers, etc. are the very ones which tend to encourage lodging. The initial rapid growth which these factors induce can sometimes be checked by adjusting the cultural practices [Ramiah, 1937, b].

Hedayetullah and Chakravarty [1941] have studied the degree of development of the mechanical tissue in the cultivated and wild species of *Oryza* grown under similar conditions (in pot culture) and tried to formulate a relationhsip between them and the lodging character. While the disposal of the elements composing the mechanical tissue is on the same plan, they are found modified in the varieties studied. According to them the highest development of the mechanical tissues is to be found in the wild species, *O. coarctata.*

The lodging problem which is rather serious in Java has been studied mainly by the examination of the actual mechanical strength of the culm. The apparatus described below, Mendiola [*loc. cit.*] has been successfully used by the Javanese workers to separate the lodging from non-lodging strains.

'This machine consists of a stand 14 inches long by 8 inches wide and 12 inches high with a flat board top. Through the top, a hole is cut $4\frac{3}{4}$ inches long by 2 inches wide. One inch from the bottom of the stand and parallel to the top is placed a platform hinged at one end. At the other end, this platform is fastened to a cut-off by a wire in such a manner that when the bucket of shots drops on the platform it automatically shuts off the flow of shot. The hopper is a 6 inches glass funnel with the stem bent at an angle of about 80 degrees. Over this is fitted a tin spout, the lower end of which is filed smooth so that the hinged cut-off will fit closely when drawn by the platform to which it is attached by a wire. The cut-off is held open and the platform is held up by rubber bands, although springs might be more desirable. The rice stem is cut to a length of 8 cm. using the part nearest to the root and this piece is placed across an auger hole in the board, the hole being 5 cm. in diameter. A small tin bucket made of a chocolate can is then suspended from the middle point of the stem piece by means of a hook made from wire about 1 mm. in diameter. Lead shot with sand is then poured into the bucket from the funnel and is automatically stopped when the straw breaks. The combined weight of bucket and the contents required to break the straw is taken to represent the strength of straw'.

Inheritance of lodging

That there are clear varietal differences with regard to the tendency to lodge has been definitely proved in many cereals, but there is dearth of literature dealing with the inheritance of lodging. Inheritance studies of this character in rice are recorded by Ramiah and Mudaliar [*loc. cit.*]. Two sets of crosses were studied by them. They made out four groups in the F_2 segregation as shown below (Table IX). Group one was definitely lodging; group two showed some tendency to lodge; in group three, the tillers were slightly open but there was no tendency to lodge; group four had plants with absolutely rigid straw.

TABLE IX

Showing segregation for lodging at the Paddy Breeding Station, Coimbatore

Cross	Groups			
	1	2	3	4
1. T. 458×T. 63	696	279	118	172
2. T. 458×T. 118	1,138		156	221
Observed	2,113		667	
Calculated 3 : 1	2,085		695	

There was some justification in combining group two with one and group three with four as group two showed a tendency to lodge while in group three there was no tendency at all. In cross II, the segregating groups were more clearly distinguishable. The behaviour of F_3 and F_4 progenies confirmed the F_2 results. The gene governing lodging may, therefore, be designated **Ld** its allelomorph being **Ld.** Study of tillering and duration in relation to lodging in these crosses showed that non-lodging nature of straw was found associated with poorer tillering and longer duration. No apparent relation could be detected, however, between plant height and sterility with the non-lodging character of the straw. These confirm the observations of Bhide [1926], who considered that standing habit was a complex but behaved as a recessive to lodging habit. He had also found that standing habit was correlated with erect flag leaf and poor tillering.

Crosses are attempted in many places to breed non-lodging habit into the otherwise valuable strains. The efforts appear to be generally successful and the apparent recessive nature of the non-lodging habit should make the breeding work easy enough.

6. SHATTERING OF GRAIN

(1) *General position*

Shedding or shattering of grain from the panicle at the time of harvest is one of the factors contributing to loss of yield in rice. It becomes important in areas where it is extensively cultivated and where the harvesting extends over long periods and also where machinery is used in harvesting. A certain amount of mechanical shedding under any circumstances is inevitable, and the aim of the breeder should be to get a type where this has been reduced to the minimum. Since threshing of rice is mostly done by human labour by beating the sheaves against a hard surface, an ideal non-shattering variety will be difficult to thresh, and thus part of the advantage gained in growing such a variety will be lost by the extra labour that may be necessary to thresh the crop. The loss due to shattering is likely to be greater in an over-ripe crop and so also in a crop that has lodged before it is ripe. A ripe crop subject to alternating heat in the day and heavy dew in the night, which usually prevails at this period, increases the amount of shattering. The practice of harvesting the crop while the straw is still green and then allowing it to dry in the fields for a few days before threshing, helps in minimising the loss due to shattering. The above, combined with the practice of stacking the dried sheaves for two or three months before threshing, makes threshing operations easier as the grains come off easily.

(2) *Variation in the character*

There are considerable differences in the amount of shattering observed in rice varieties. The worst form of shattering is exhibited by the wild rices. The grains shatter and come off the panicle even before they are ripe and any collection of grain must be done at the half ripe stage. At the other extreme there are certain varieties where severe beating makes the whole panicles and panicle branches come off rather than individual grains. Even by a very rough examination at the time of harvest, cultivated varieties may be classified into groups with varying amounts of shattering of grain. In some of the varieties the loss of grain due to delayed harvests has been estimated at 5 to 12 per cent at Coimbatore [Ramiah, 1937 b]. This loss can be very much higher in some tracts where the trouble is mainly due to the contamination of the cultivated rices by the wild rice and the presence of natural hybrids between the two as rogues in the crop.

(3) *Anatomical studies*

The process of shattering of the grain depends mainly on the nature of attachment of the caryopsis in the head. This attachment consists of a depression at the base of the fruit and a small projection of the stem which fits in this depression. Graham [1913] observed that the character of the upper ends of the pedicel, which he calls facet, is of special interest because, it is found to be related to 'tightness' (non-shattering) of grain. In ordinary non-shattering varieties the facet is cup-like and in the shattering types it is ciliate, short with erect hairs on the margins (Fig. 5). Takenouchi [1924] reports that at the junction of rice spikelets and their supporting stalks there is a special tissue consisting of one to three layers of lignified thin walled cells. In rices that shatter easily, these cells develop and dry up early, whereas in rices that shatter less easily they do not dry up so early. In a few rices it was noted by him that no abscission tissue develops at all, and in such cases the grain separates from the stalks with great difficulty. Yamasaki [1928] confirms the observations made by Takenouchi and stresses that the time of formation of this abscission layer determines the nature of shedding. Chalam [1942] holds that in the cultivated varieties the abscission layer is not fully formed and that two bands of lignified cells all round the central vascular bundle of the pedicel are not acted upon by the chemical reaction of the abscission cells. Certain amount of mechanical strength is also received by the shape of the joint which is like a ball and socket joint. But in wild species, *O. sativa* var. *spontanea* and *O. coarctata*, the abscission layer is formed much earlier and is more complete.

Bhalerao [1930] notes that the cultivators believe that such conditions like (i) stiff clay soil, (ii) large quantities of humus, (iii) stagnant water, (iv) more water in the fields at ripening time and (v) rapid drying of ear heads after maturity, contribute to shattering. It has been observed in Madras that varieties that do have a tendency to shatter, show it very much more when grown in out of the appropriate season. The formation of abscission layer is perhaps influenced by weather conditions. Some early varieties are found to shatter more when the harvests come in summer than in autumn. Similarly, varieties shatter more when grown in higher altitudes than in the plains.

(4) *Association of shattering with other known characters*

Awned rices are generally believed to be less shattering than those without awns but actual counts in a segregating family did not show any genetic relationship between the two characters, [Mendiola *loc. cit.*]. Work at Coimbatore (unpublished records) however did show that there was some association between these two characters in crosses between wild awned rice and cultivated awnless rice. The shape of the grain also shows some relationship with the shattering character. Generally, varieties with a round shape of grain show more shattering than those with long or oval shape of grain. Similarly the ripening black character of the lemma and palea shows some association with shattering.

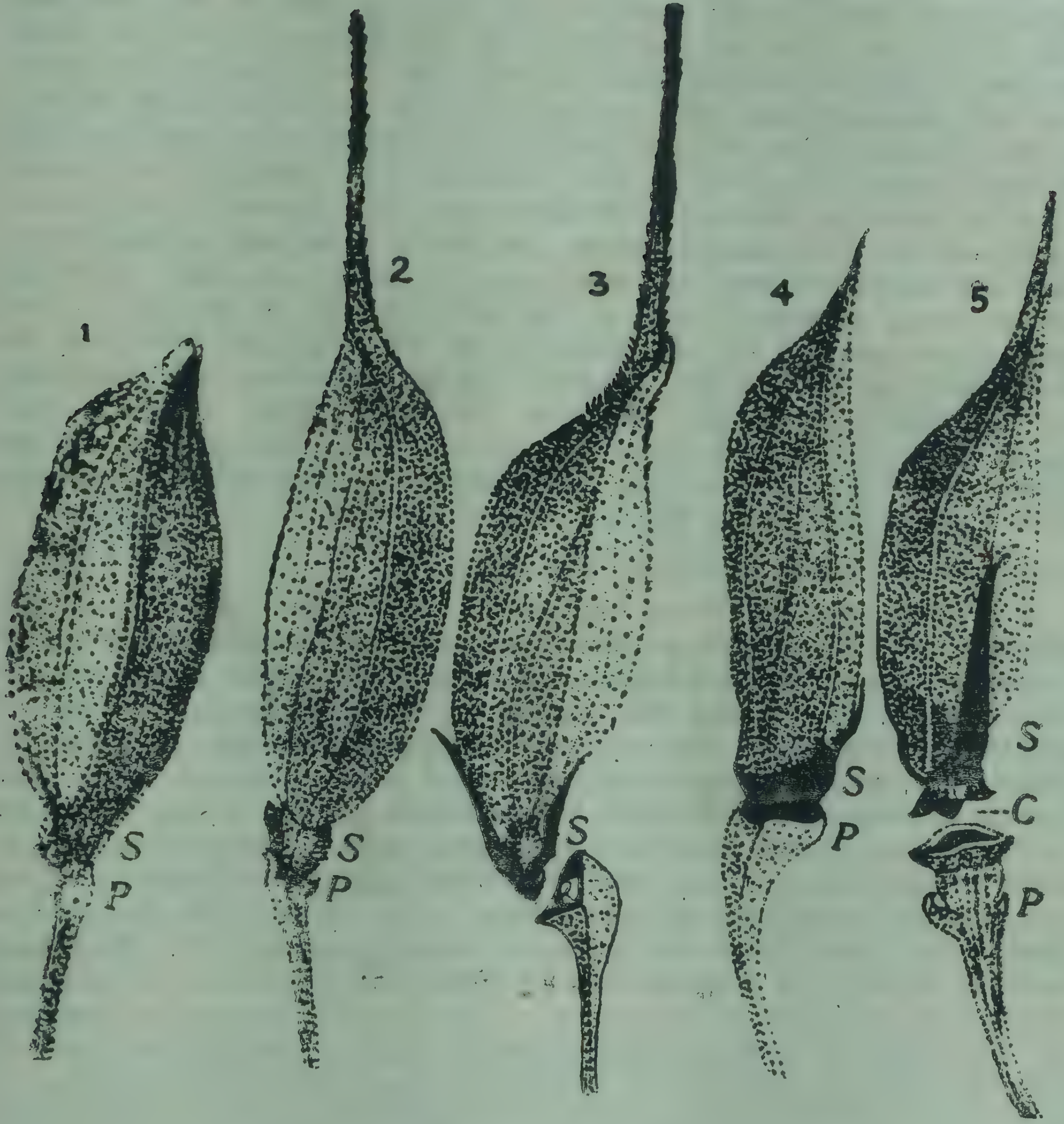


FIG. 5. Anatomical structure of spikelet base.

1. Spikelet of *O. sativa.*
2. Spikelet of *O. fatua* early.
3. The same after ripening when the pedical separates from the spikelet.
4. Spikelet of *O. Coarctata,* early stage.
5. The same after ripening when pedical separates from the spikelet.

(After Chalam, 1942).

(5) *Shattering, a special problem of some tracts*

In certain tracts of India as in the Raipur division of the Central Provinces and the *Mallad* tract of the Bombay Presidency the problem of rice shattering is a serious one. The wild rice, *O. sativa* var. *spontanea*, is always to be found in the swamps and lowlying spots in the tract and during floods the seeds get transported to the adjacent cultivated fields. Rice being broadcast in these areas, the wild rice also germinates and grows along with the cultivated type and there is free natural crossing between the two. These crosses are not easily distinguishable from the cultivated type except when they come to form ears and start shedding their grains, and by that time the mischief is already done. The cultivators do practice rogueing out the wild plants in these areas but it is not very satisfactory as further contamination may, also take place. Moreover, the shattering character being dominant adds to the difficulty. It is possible to find varying forms carrying the characters of the wild rice and there may be plants which for all practical purposes do not have any wild character except this shattering nature [Bhalerao *loc. cit.*]. The difficulty has, however, been overcome by breeding suitable types with pigment on the vegetative parts so that the wild rice carrying no pigment can be easily identified and rogued out in the early stages.

(6) *Mechanical devices to estimate shattering*

A pressing problem of the Philippine rice industry is said to be the production of a less-shattering variety and this has necessitated the use of a simple and quick method which would indicate the degree of shattering in several cultures. A machine that was in use at the Philippine College of Agriculture to determine the degree of shattering has been described by Mendiola [*loc. cit.*] ' The apparatus consists of a square funnel each side of which is twentyfour centimeters long. Across the top of the funnel are stretched strands of wire about one centimetre apart. The rice panicles are allowed to fall from a definite height on to the grating thus formed, and the impact results in shaking off part of the grain. Under the funnel is a receiver where the grains are collected when they fall off. A mature panicle is placed on a platform in such a manner that when it is released, it falls down vertically on the centre of the funnel. The grains separated from the head are collected and counted. The shattering percentage is calculated from the number of collected grains and the total number of grains in the panicle and the quotient multiplied by 100 '. This machine was tried at Coimbatore, but it was found that the method involved difficulties in controlling the way in which the panicle fell, and the surface of impact of the panicle varied with the method of its fall. After some preliminary trials a special apparatus was designed by Hanumantharao [1935]. The apparatus consists of an inclined plane and a weighted glass roller about 500 gm. which is allowed to roll over the rice panicle placed on the plane. Due to the impact of the roller over the panicle, a number of grains get shattered and the percentage of the shed grain to the total number of grains is taken as a measure of the degree of shattering. This instrument has also certain defects. For example, the total surface of contact between the roller and the panicle is subject to variation according to the density of the panicle. But where no complications arise due to differences in the length of the panicle and its density and size of grain, this device can give satisfactory results. This was used in estimating shattering in a large number of F_2 and F_3 families of crosses specially made for studies on its inheritance.

Hamid and Baker [1939] invented a small device to estimate the relative position of rice varieties with regard to the shattering character when bulk samples were available. A sheaf of rice standardised as to weight and length is fixed into a wooden frame which can be raised or lowered on a horizontal axil. The frame together with the sheaf is first raised to the vertical position and then allowed to fall under its own weight. The heads of the sheaf strike an inclined board and a certain amount of grain gets detached. The measurements of the frame used by them are given below :

Inside breadth of outer frame work—2 ft. 5 in.
Height of axil above ground—4 ft. 4 in.
Length of frame holding axil—2 ft. 8 in.
Internal width of frame lifting sheaf—11 in.

The sheaf is three feet long and weighs 8 lb. and receives 21 strokes. That there may be a number of defects in the arrangements the authors admit, but it is very difficult to get all factors standardised properly for a determination of this kind. But it may be mentioned that the relative position of varieties as indicated by the results of these tests coincided in general with the opinion of the practical cultivators regarding their degree of shattering.

(7) *Inheritance studies*

Ramiah [1934] studied the inheritance of this character in a cross between a cultivated rice and a wild rice (with complete shattering). The ± was almost similar to the wild parent in shattering and in the F_2 generation a segregation of 3 shattering (some progenies definitely less shattering than the typical wild type) and 1 non-shattering was obtained. Bhalerao [*loc. cit.*] also reports from studies of natural hybrids with wild rices, that shattering was dominant to non-shattering but that more than one gene was involved. Kadam [1936, b] from studies of a cross between a wild rice and a cultivated rice realised a 15 : 1 ratio of shattering to non-shattering in F_2 with complete shattering in F_1. Perhaps two genes Sh_1 and Sh_2 govern shattering and what Ramiah had observed in his studies might be one of these.

The character was studied quantitatively by Ramiah and Hanumantharao [1936] using the inclined plane already described in a cross between two varieties, one with a mean shattering of 3.54 ± 0.13 grains (range 0-10) and the other with a mean of 34.3 ± 0.53 grains (range 17-56). The shattering was somewhat intermediate between the two parents in F_1. Shattering was estimated in F_2 population of 537 plants. The mean shattering was 12.34 with a high coefficient of variation, but the variation was not transgressive. Fifty progenies were grown and studied as F_3s and again 100 progenies as F_4s. The coefficients of correlation between F_2 and F_3 and between F_3 and F_4 were + 0.48 ± .023 and + 0.72 ± .032 respectively. In F_4 all the families with a high degree of shattering were breeding pure and segregation was apparent only in some of the families with an intermediate degree of shattering. It is clear that while the inheritance is not simple, the number of genes involved cannot be many.

Sethi [1933] studied the hybrid progenies of crosses of *sathi*, an enclosed ear type, with greater grain shattering than many other varieties, with several other pure lines and has reported that the shattering character was partially dominant to non-shattering. The degree of shattering varied greatly making the classification between shattering and non-shattering habits far from simple. There were some families in which the grains were so tenaciously attached to the panicles, that proper threshing was greatly hindered, the grains refusing to separate from the panicle even though, the force of threshing was enough to dehusk the grain. He concluded that more than one gene was concerned. Jones [1933], however, realised a 3 : 1 ratio of shattering to non-shattering in the F_2, the determination being made qualitatively on the ease with which it was possible to strip the grain off the panicle. Kato [quoted by Matsura, 1933] found that non-shattering was more pronounced in F_1 and in F_2 a 3 : 1 of non-shattering to shattering was obtained, the converse of what has been observed by other workers. Gagolinan [1936] had found that from a commercial variety of rice called *Apostol,* it was possible to isolate strains with strong rachillae. He found decided correlation between the number of ear bearing culms and strength of rachillae, i.e. the more ear bearing culms the plant produced, the stronger the rachillae.

7. STUDIES ON FLOOD RESISTANCE

In certain parts of India, particularly in the deep valleys of the Brahmputra and the Ganges, (Assam and portions of Bengal) and in the deep creeks along the sea coast as in Western India and in Orissa, the problem of rice growing is attendant with great difficulties as one has to contend against floods of varying depths and periods. In Assam the floods are said to reach a maximum height of even twentyfive feet every year in June and July and the fields continue to remain flooded for a long time afterwards. Along the sea coast, the floods are intermittent and there is the additional difficulty of salinity to face. In the ill-drained areas of the interior, the floods may be intermittent, with no floods at all in certain seasons depending upon the rainfall and drainage of the surrounding areas. Thus each flooded area has its own peculiarities which have to be studied. In tests conducted in Japan, the period of resistance to submersion, except where the plants recovered with difficulty, was eight days under water at a temperature of 30°C. and only two days at 40°C. Owing to the technical difficulties of studying the varieties grown under floods no extensive data on this subject are available in India.

(1) *Highly flooded areas*

In the typical flooded areas of Assam and Bengal, cultivators grow what are called long stemmed *amans* which, under favourable conditions of gradual rise of water level, give a satisfactory crop. A wild rice called *jorhan* belonging to the species *O. officinals* is found in some of the heavily flooded areas of Assam and this, it is thought, might have given rise to some of the *aman* varieties as these resemble more or less the wild rice in such characters as long stems, aerial adventitious rooting and the poor quality of grain.

(a) *Growth studies.* With a subvention from the Indian Council of Agricultural Research, a research station was opened in 1934 at Habiganj in Assam for the study of the deep water rices and problems connected with them. Preliminary observations with regard to their variation in morphological characters, the optimum age of seedlings which could survive floods, resistance to duration of floods, etc. have been completed. The results available so far have shown that : (1) seedlings which are somewhat older by the time floods set in show a greater resistance to submersion ; (2) the initial height of the seedlings is no index to their capacity to resist flood submersion and (3) yield and flood resistance are not correlated and a rapid growth is not necessarily accompanied by high yield. Daily growth of as much as eight to nine inches in height is not infrequent when water rises are abrupt. But if this state continues over several successive days, the vitality of the plants is seriously impaired and in some cases the whole crop is lost. During the monsoon when there is water in fields, plants remain in a stable equilibrium at a height of two to two and a half feet above the ground level ; when the level of water rises this equilibrium is upset and plants attempt to restore it by growing in height which takes place by production of long internodes ; when the rise of water is low, vertical growth practically ceases as is evident from the formation of very short internodes, and nodal branches are produced which under favourable conditions form ears and contribute to yield [Majid, 1937].

(b) *Varietal differences.* Even under complete submersion, varieties have been found to grow. Growth under water ceases after a particular length of time, when plants begin to decay. If flood water becomes stationary after an abrupt rise, some varieties which may have been previously submered, grow and manage to come up above water level. Under submerged conditions, the rate of growth increases with the age of plant from two to four weeks ; after four weeks' age the growth gradually falls, and this fall in growth is particularly marked in plants ten weeks old.

An intensive study of flood resistance has yet to be taken up. A few recommended types have shown resistance only up to eight feet of water and the actual method of studying flood resistance and determining the causes of such resistance are still to be explored. The chief requisite of a flood resistant variety in these areas is its ability to grow with the rise in water level and keep itself clear above its surface. The ability to tolerate submergence of various durations in a great *desideratum.* It is at once evident that these aspects necessitate a good grasp of the physiology of rice plant, and results are bound to be slow in this study.

(c) *Anatomy of flood resistant types.* A beginning has been made to study the anatomy of the stem of the several varieties which show tolerance to flood. The area of the air passage calculated as percentage of the total area of cellular tissue and its relationship to the capacity to resist flooding was studied in twenty pure lines. The correlation coefficient between ratio of air space and resistance to submerison varied from $+0.398$ to $+0.408$. The study of sclerenchymatous tissue did not reveal any marked differences. Hedayetullah and Chakravarty [1941] have found that subcortical air passage was developed to the highest degree in *O. officinalis* and *O. coarctata.*

To bring the character of flood resistance into the orbit of genic analysis will be matter of time. Varieties which are completely resistant to high floods of 20 to 25 feet have not yet been met with in the cultivated forms. The manifestation of this extreme capacity is to be realised in the wild species *O. officinalis,* and to study the inheritance, crosses have to be made between *O. sativa* and *O. officinalis*. So far all attempts to obtain fertile F_1 hybrids in this cross have proved futile.

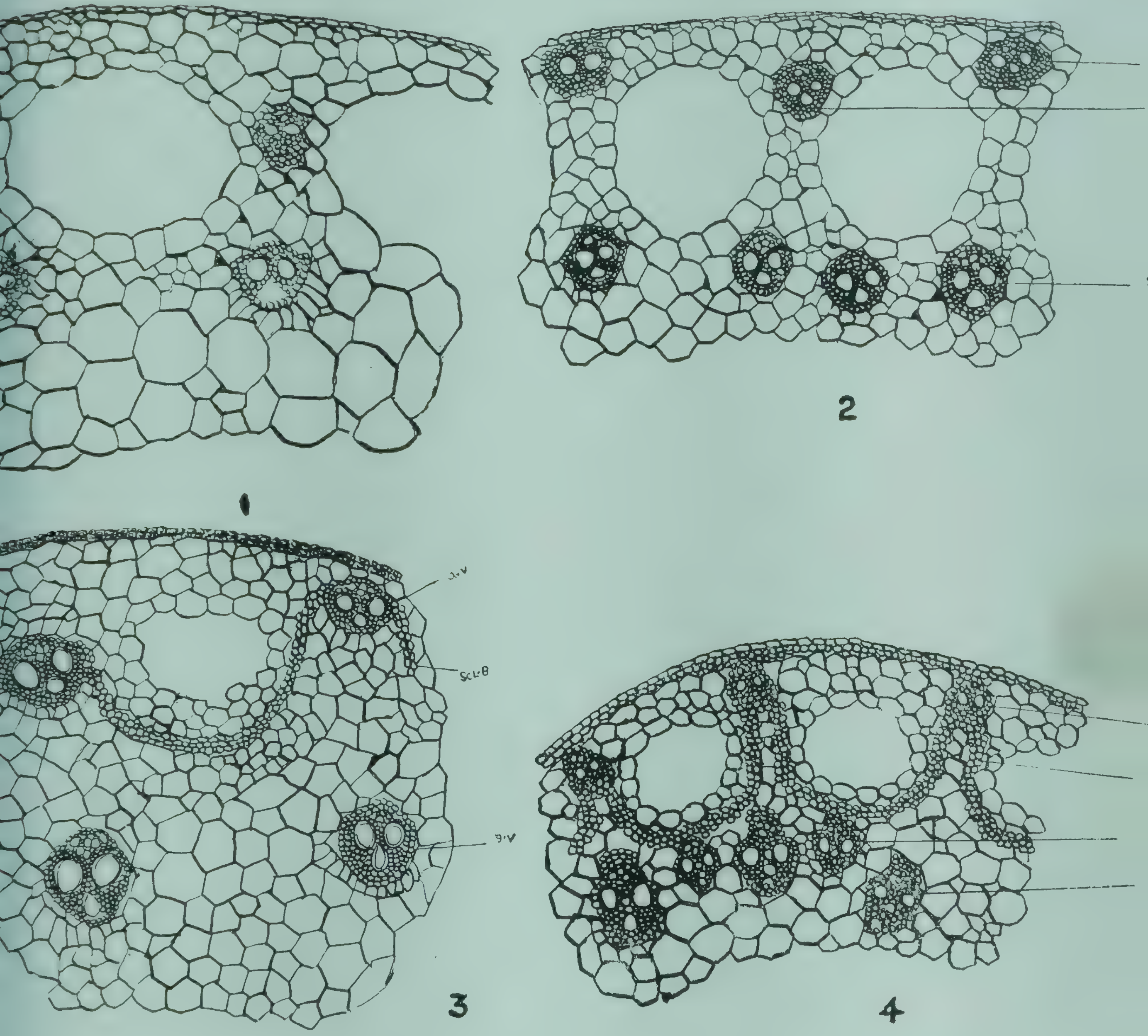
(2) *Intermittently flooded areas*

As already stated the floods that occur in other parts of India under ill-drained conditions differ from those described above in that they are only five to six feet deep and are intermittent. Combined with this is the existence of a current in these areas which subjects the plants to a mechanical action as if uprooting them and washing them off. Thus a suitable variety to resist this kind of flood must combine in itself (1) tenacity of the stem to stand strong current of water which would include studies on the root system and anatomy of the stem with special reference to tensile strength and (2) capacity to survive continued submergence which means the power to regenerate by throwing secondary tillers when the main shoot succumbs. The situation is again complicated from the fact that in certain season, floods may not occur in the later stages by the monsoon finishing abruptly, and the useful flood resistant types naturally suffer from drought due to absence of water. The typical deep water rices of Assam are not suitable here as they grow only under continuous and high floods. It may be mentioned that the wild rice *O. longistaminata* commonly found in these areas admirably possesses these qualities. Graham [1913] has observed that the danger of flooding to which this wild rice is subject to in *bhils*, and the late maturity occurring long after the seasonal rainfall had ceased, make this species both flood and drought resistant. From preliminary studies made at the Rice Research Station, Cuttack, it has been found that certain varieties show a greater percentage of survival after being subjected to floods than certain others.

(a) *Anatomy of the stem.* Parija [1941] studied the stem anatomy of some of these varieties (Plate XXV). A sclerenchymatous band around the cuticular lacunae which varies in size was observed in most of the selections. In the types which showed greater resistance to floods, this band was supported by an additional cap of sclerenchyma at the lower pole of the peripheral bundles which are one to two cells in thickness. In cross sections of leaf sheath, it was observed that flood resistant rices develop sclerenchymatous tissues when they are subject to prolonged submergence under water.

It is interesting to compare the stem structure of the cultivated flood resistant rices with that of *O. longistaminata* and *O. coarctata* common in the marshes of this tract. In *O. longistaminata*, the band is not present; both the interior and exterior bundles are of the same size unlike the ordinary varieties, and each of these bundles is surrounded by a double layered sclerenchymatous sheath in contrast to the single layered sheath in the common cultivated type. The stem of *O. coarctata* resembles in structure the stem of the flood resistant types.

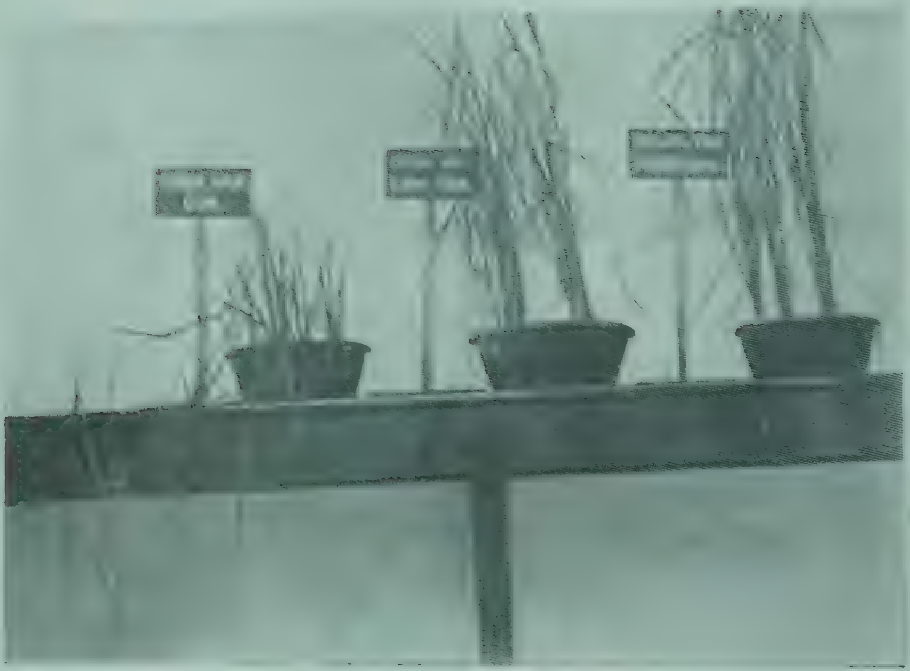
(b) *Tensile strength of stem.* A simple way of determining the bending strength was evolved by Parija [*loc. cit.*]. A bit of stem from the first top internode, six inches in length was cut and this was supported horizontally by means of a retort clamp. A scale fixed in the middle of this piece showed the deflection 'a' from the horizontal that occurred when a weight of 400 gm. was put on, in the scale. An additional load of 100 gm. is put in the pan and the amount of further bending 'b' was



Stem anatomy of normal and flood resistant types

1. Transverse section of normal rice.
2. ,, ,, *O. longistaminata.*
3. ,, ,, flood resistant type F.R. 43-b.
4. ,, ,, *O. coarctata.*

(With permission of Prof. Parija, Cuttack, 1941) Unpublished records.



Effect of treating germinating seed for flood resistance

Pots were submerged for 24 days under water. Note treating seed with low temperature under anaerobic conditions has resulted in some resistance to submersion.

(After Parija from unpublished records).

noted. The additional weight was removed and the recovered portion 'c' was noted. The elasticity of bending $\frac{b-c}{b}$ was calculated for the different varieties and the values for a dozen varieties are given in Table X.

TABLE X.

Showing bending strength of different rice varieties at Cuttack

Variety	Reading for first 400 gm. (*a*)	Reading after the addition of 100 gm. (*b*)	Reading after the removal of the weight (*c*)	Bending (b-c)	Elasticity of bending $\left(\frac{b-c}{b}\right)$	Presence or absence of the band
F.R. 44-B ..	0·14	0·24	0·014	0·226	0·94	Two celled band present
F.R. 44-A ..	0·30	0·44	0·09	0·35	0·79	Band present
F.R. 14 ..	0·47	0·80	0·21	0·59	0·73	Band absent
F-R. 43 ..	0·30	0·70	·20	·50	0·71	Band present
Kania ..	0·38	0·60	0·28	0·37	0·61	Band absent
F.R. 7-A ..	0·60	1·10	0·50	0·60	0·55	Do.
F.R, 12-A ..	0·50	0·83	0·40	0·43	0·51	Do.
F.R. 7-B ..	0·98	1·20	0·68	0·54	0·45	Do.
F.R. 27-A ..	1·06	1·63	0·92	0·71	0·43	Do.
F.R. 2 ..	0·64	1·35	0·65	0·70	0·42	Do.
F.R. 13 ..	2·60	3·40	2·58	0·82	0·24	Do.
Ordinary ..	2·90	4·30	3·00	1·30	0·30	Do.

It was observed that the selection F.R.44-B, in which the band was of two cells in thickness, had an elasticity of 0.94 cm. for every centimetre of bending under a pulling load of 500 gm. weight. Two other resistant selections F.R.43 and F.R.14 with and without a band had an elasticity of 0.71 cm. and 0.73 cm. respectively; perhaps the lignin content of these cultures irrespective of the amounts of sclerenchyma they possess, is responsible for their resistance to flood. In field observations all these selections have been observed to stand the flood current better than other selections. Thus this physical constant may have something to do with the mechanical resistance that the different varieties offer to the lateral force of floods.

(c) *Educating plants for flood resistance.* It was assumed by Parija [1938] that there was no sunlight passing through beyond a depth of six cm. of water under submerged conditions. There was also difficulty in the supply of oxygen under submerged conditions as there was no subsoil drainage by which the roots could be supplied with oxygen. On the analogy of homeopathic principle of *similia similibus* in the treatment of ailments, Parija [*loc. cit.*] started experiments to see how far educating the germinating rice seed to develop in darkness and in absence of oxygen would induce flood resistance where these two factors would appear to be the limiting ones for survival. Seeds were soaked in water for twentyfour hours to initiate germination, and they were divided into four groups and each group was treated as shown below :—

Treatment 1.—Kept at 4°C. in a Kelvinator for six days.

Treatment 2.—Kept in Kelvinator at 4°C. for three days and then kept in a current of nitrogen for another three days.

Treatment 3.—Kept only in a current of nitrogen for six days at room temperature, and

Treatment 4.—Control.

The seeds were first sown in small pots and later transplanted in larger pots when the seedlings were three weeks old. When the seedlings were sixty days old they were submerged for 10, 14, 19, 24 and 29 days respectively in a tank six feet deep, with water about two feet above the seedlings. Another set of pots when the seedlings were eightyfive days old was subject to submersion for similar periods. The results of these preliminary experiments showed that low temperature and anaerobic treatment might prove effective in inducing resistance to submergence (Plate XXVI). The pure line F.R. 27-A which did not resist submergence in 1938, had improved its resistance after this treatment for three years.

As a result of submergence, some morphological peculiarities were observed such as (1) the swelling of leaf sheath with the formation of parenchymatous tissues; (2) considerable elongation of the stem and (3) formation of secondary tillers from the upper node with an angular sheath between them and the primary tillers.

It would follow from what has been said here that the growing of a rice crop in the flooded areas is, under the present conditions, very precarious. Even in breeding programmes dealing with the evolution of flood resistant rices, the problem should be a long range one requiring considerable equipment and special facilities. Since the work is involved with physiological problems, it should be useful to carry out the work in cooperation with a good plant physiologist.

8. STUDIES ON DROUGHT RESISTANCE

The term, drought resistance, is applied rather loosely to describe different situations. Plants which are suitable for cultivation in the arid regions can be said to be really drought resistant. The suitability of certain varieties to droughty conditions may be due to their being early ripening and escaping drought. There may be other varieties which use the soil moisture economically and thus develop well with the small amount of moisture available. These cannot be really drought resisting but may be termed drought escaping or drought evading varieties. According to Maximov ‘the basis for drought resistance is the capacity of plants to endure and recover readily after permanent wilting with the minimum of damage to the plant itself or to the yield produced’. The capacity to withstand drought is said to depend upon tolerance to three factors, viz. water loss by cells, increased cell temperature and increased salt concentration. In India, in many parts of which the cultivation of rice is governed by limitations of rainfall, knowledge of the relatively greater efficiency which some varieties possess in the use of water is of fundamental importance in the selection and breeding of strains suited to different ecological conditions. While phosphates tend to reduce transpiration [Hector, 1927; Singh 1940], nitrogenous manures do not appear to have any effect.

It has been a common observation that certain varieties grown under restricted conditions of water supply thrive better than others, and this would show that the capacity to resist conditions of drought are genotypic and governed by specific genes in the varieties concerned. There is no doubt that the production of drought resistant varieties necessary for tracts of uncertain water supply will be rendered easier by a knowledge of the inheritance of this character.

In Bengal, Hector [*loc. cit.*] found that there was a distinct indication of the osmotic pressure of the cell sap of high land *aus* varieties being higher than that of the transplanted and deep water *aman* rices. There did not appear to exist any appreciable difference in osmotic pressure between early and late *aus* as also between transplanted and deep water *amans*. Onodera [1930] showed that under drought conditions upland rice varieties showed remarkable elevation in osmotic pressure of cell sap whereas low-land varieties under similar conditions did not show any. Skazkin [1936], however, warns that since osmotic pressure of a variety was influenced by environment, a good deal of care should be exercised in taking this as an index of drought resistance and the methods required more study and greater refinement. Ivanov [1937] has described a method of selecting for drought resistance in wheat, rice and millets which consisted of soaking the seed in water at 15-16°C. for four hours and immediately subjecting the swollen seeds to temperatures of 45°, 47° and 49°C. The percentage of germination obtained after such treatment corresponded closely to the drought resistance, the greater the percentage of germination, the greater being the drought resistance.

Other differences have also been noted by workers in the physiological activities of the drought resistant high land varieties as compared with low land types. Yamasaki [1929] soaked seed of different varieties of rices in a solution of potassium chlorate for two days at 25°C. and then germinated in water; he found that upland varieties germinated and flourished while the low land ones were damaged on germination. Alam [1939] tested this in rice varieties of Bihar by subjecting them to germination in 1.8 per cent solution of potassium chlorate and found from pot cultures that these varieties which showed a fair amount of germination withstood also long periods of drought. It was also shown by him that early and medium varieties tolerated drought better than late varieties.

The results of Alam's transpiration studies on rice may be summarised as follows:

(i) Transpiration ratio was a varietal character; (ii) Total water lost was markedly affected by the degree of saturation of soil moisture; (iii) For a given variety the transpiration ratio was constant for all degrees of saturation, and (iv) Phosphate manuring lowered transpiration rate. It follows that in a year of low rainfall, a full rice crop can be reaped on land manured with P_2O_5 which would otherwise not contain sufficient moisture to mature the crop. Transpiration coefficients of drought resistant types are smaller than for low land types [Onodera, 1933].

A Russian worker, Erygin [1934] has found that dry seeds of lowland varieties contained greater quantities of soluble carbohydrates than those of upland rices. Seeds of a low land variety could absorb oxygen dissolved in water and respire more vigorously; the formation of leaves and formation of roots occurred earlier in low land rices than in upland ones under low current of oxygen. Van der Stok [quoted by Hann, 1914] found that varieties with short rough hairs on leaf were more drought resistant than smooth leaved ones.

Some differences in the anatomical structures have also been observed in varieties which differed in their degree of resistance to drought. In rice, Onodera [1930] observed that in low land rices 'the sterome' or mechanical tissue was well developed on the lower side of the leaf while in some of the upland rices its development was much feebler. Alam [*loc. cit.*] observed that the varieties which stood drought when grown under artificial conditions of irrigation had fewer stomata and the stomata cells were also smaller. Ideko [1938] found that low land rice varieties had bigger coleoptile than upland varieties. The first leaf in upland varieties emerged within five days after germination, but in the low land varieties it did not until after eight or nine days. The first leaf was also longer than the coleoptile and the difference might reach a length of ten mm. in the upland varieties while in the low land varieties the first leaf was invariably shorter than the coleoptile.

An interesting experiment, vernalisation at high temperature, was started by Parija [1941 and 1943] to induce drought resistance in rice varieties by pretreatment of seeds. Rice seeds were soaked in water for twentyfour hours when the basal portion of the husk at the midrib becomes opaque. The seeds were then air dried for six to eight hours and then in electric oven at 40 to 42°C. for twentyfour hours. These seeds were then cooled and sown in pans. Even at the seedling stage the treated and untreated seedlings manifested differences in drought resistance. The seedlings were later planted in pots using weighed quantities of soil; a measured quantity of water was added so that, at the time of planting, the soil had 25 percent level of moisture. The lids of the pots were sealed so as to prevent rain water entering. These pots were watered at intervals of 4, 8, 12, 16 and 20 days, adding each time as much water as was lost in transpiration, i.e. the weight of the respective pots was kept at the same level as at the time of planting. The plants in 16 and 18 days pots both in the treatments and controls perished. The results of the pot culture test are given in Table XI.

TABLE XI

Results of pretreated seeds in pot culture experiments, Orissa

Interval of watering	Quantity of water transpired in gm.		Mean yield in gm.		Water transpired for production of unit dry matter	
	Control	Treated	Control	Treated	Control	Treated
4 days	6464	5378	1·96	2·076	832	642
8 days	5162	3666	1·07	1·17	785	689
12 days	4891	3565	1·30	0·825	843	775

The following conclusions may be drawn from these figures : (1) Water requirement of treated plants was less compared with that of the control. (2) Control plants gave higher transpiration coefficient. (3) Treated plants gave more weight of grain in the eight day treatment. It was found that the treated plants flowered 8 to 10 days earlier than the controls.

Alam [*loc. cit.*] investigated the water requirements of a number of pure lines in Bihar and found that those selections which had a low transpiration rate withstood permanent wilting to an appreciable degree, survived up to 90 to 100 per cent and gave 35 per cent higher yields than the pure lines with higher transpiration coefficients.

Mention may here be made of the fact that the wild rice *O. longistaminata* has been found to resist drought better than the cultivated rice. In the Central Provinces the trouble due to the wild rice *O. sativa* var. *spontanea* which occurs as a pest in rice fields, assumes more serious proportions in a year of scanty rainfall than in one of good rainfall ; it tillers more rapidly and profusely than the cultivated rices, showing that it thrives better under unfavourable moisture conditions. Srinivasan *et al.* [1941] were able to isolate drought resistant forms from crosses between cultivated rice and the wild rice, *O. longistaminata.*

9. STUDIES ON RESISTANCE TO SALINITY

There are large areas in the coastal parts of North Konkan in Bombay Province, the 24 Paraganas and Khulna in Bengal, parts of Malabar, Travancore and South Canara of the Madras Province, the coastal tracts of Orissa, parts of Sind, etc. where rice has to be cultivated in land subject to salt water inundation. This is however different from the situation obtaining in parts of the Punjab where due to the rise of water table vast alkaline areas are formed every year whose reclamation in the earlier years is done by growing certain special rice varieties, such as, *Sathra* and *Jhona.* In the coastal areas, possibly by means of natural selection the varieties being cultivated are somewhat adapted to saline conditions and these are generally of a poor quality. Most of these areas are low in level, (only a few feet above the sea level) and are, therefore, subject to submersion by tides during certain seasons of the year and hence the problem becomes complicated by the necessity for breeding salt resistant varieties which can resist floods also. Prevention of tidal floods by an elaborate bunding system as is practised under '*Cole* and *Kaipad*' cultivation obtaining in the back waters of Malabar [Ramiah 1937, b] may be developed depending upon the value of the land and the nature of irrigation facilities available. Reclamation by the use of chemicals, by frequent washing out the salts by flooding with fresh water and by improving the underground drainage have been practised here and there with some success. Application of gypsum has proved useful in reclaiming salt lands. Certain saline areas in Travancore are said to have improved by the application of large quantities of green leaves from trees of tamarind *Tamarindus indicus, Phyllanthus, etc.* Vast areas in the coastal tracts of Godavary and Kistna districts in Madras are reclaimed by frequent flooding of the area with fresh water and providing large open drains across the fields.

Physiological studies connected with salt resistance made by Alam [1939] and Parija [1941] have proved somewhat interesting and are recorded here. Two methods of inducing plants to resist salinity were tried. The first one consisted of pretreatment of the seed; seed was soaked salt and homeopathic principle in 0.0000001 per cent solution of common salt and then germinated in 1.5 per cent salt solution. The seed first soaked in salt solution gave 60 per cent germination whereas the control gave only 20 per cent. germination. The second method consisted in educating the rice plant to tolerate salinity. In the first season, Alam planted seedlings of ordinary rices, the seed of which was pretreated and germinated in pots containing common salt solution with a concentration of 0.1 per cent. The produce of those plants which tolerated salinity and gave more yield was treated in the next season with a slightly higher concentration of salt solution. Every season these seeds were compared against seeds which were directly treated with the same strength of salt solution that season. It was found that the seed, repeatedly treated, showed better germination and greater toleration to salinity than the seed treated directly. In four years' time 'the gradually treated seeds' which were germinated in 0.45 per cent salt solution tolerated the concentration of salt quite well. Alam also found that rice seedlings soaked in 0.1 per cent salt solution tolerated salinity when grown in pots containing 0.35 per cent of salt.

Parija adopted a slightly different technique. Seed of three varieties of rice was first soaked in 1.7 per cent saline solution for three days and the seedlings were transplanted in pots with 2 kg. of air dried soil in each. Saline irrigations at different intervals and of different concentrations were given. A control pot was also included. The results indicated that: (1) there was differential response to the treatment in different varieties and (2) the treated seed tolerated a greater amount of salinity than control in each of the three varieties tested. It was further observed that as the dose of salt concentration was increased small glistening drops exuded from the surface of the leaves which on drying were found to be crystals of sodium chloride.

Anatomical studies were made of salt resistant and ordinary rices by Parija [*loc. cit.*] and the following conclusions were drawn by him: (1) The exodermis layer of roots of salt resistant rice was considerably suberised unlike that in the ordinary rice. (2) Even ordinary rices when irrigated with salt solution developed suberin in the thick root. (3) The chloride content of ordinary rice receiving irrigation with salt solution increased rapidly while in salt resistant rice the chloride content in the grain in spite of the salt solution irrigation did not rise over the control with ordinary irrigation. (4) The chloride contents in shoots of salt resistant type was higher than that in the shoots of the ordinary variety.

By a process of natural selection, certain varieties are found to tolerate a higher percentage of salinity than other varieties. It is, therefore, probable that there exists a definite trait governed by specific gene or genes which are responsible for resisting salinity. Salinity is injurious specially when the plants are young and if the seedlings once establish themselves there is not generally much trouble later. The physiological aspect concerned in saline resistance appears to lie in the high osmotic pressure of the cell sap which will withstand plasmolisation by the saline soil solution. As yet no critical investigations have been taken up with regard to the physiology of resistance, and much less on the interitance of saline resistance. It can be tackled only when a suitable technique of measuring saline resistance in individual plants is available.

Practical breeding work in evolving saline resistant varieties is being conducted at Coimbatore, Orissa, Bengal, Travancore, etc. mainly by selection of survivals in saline areas. The varieties that are generally grown in the saline soils are coarse and have red rice. There is a popular feeling that the ripening black character of the lemma is associated with saline resistance, the only available ground for this belief being that most of the saline resistant types have ripening black lemma. Hybridisation to improve the yield, texture and quality of these rices by crossing them with better sorts is in progress in the experimental stations at Madras, Bengal and Travancore. The work is yet in the preliminary stage. Certain varieties grown in Indo-China are reported to stand salinity fairly well and these are being tried at Barisal in Bengal.

It has already been reported that the problem of salt resistance is complicated in that certain of these areas, along Orissa coast for example, get also submerged due to tidal effects and varieties that are salt resistant ordinarily do not resist submergence also. But the wild rice, *O. coarctata* flourishes in highly saline water in the mouths of estuaries. Crosses between this wild species and cultivated rices have not succeeded so far. There is no doubt that more physiological and breeding studies are required. Any useful results derived from such studies should make rice cultivation in these areas less risky and thus help in increasing the production in the country.

10. VERNALISATION AND PHOTOPERIODISM

Vernalisation

No account of recent progress in the rapidly developing science of plant genetics will be complete without a reference to the new line of development in vernalisation evolved by the Russian physiologist, Lysenko. The general principles of vernalisation and its possibilities are dealt with in Bulletin No. 17 of the Commonwealth Bureau of Plant Breeding and Genetics [Anonymous, 1935]. Several workers in India have been investigating the utility of developmental physiology in Indian agriculture and the results available so far are dealt with here.

It has been said that vernalisation has a role in plant breeding. Plants intended for crossing according to the Russian scientist, Bruman [1937], may be selected on the basis of a biological analysis through vernalisation. Such analysis reveals the particular developmental stage at which specific responses to the local environment are reflected. The selection of parent plants is then made with a view to obtaining a compensatory interchange of satisfactory developmental stages. For example, two varieties of wheat one of them with a slow ‘ thermal ’ stage and a rapid ‘ light ’ stage, and the other with the rapidity of these stages reversed, give a hybrid combining the rapid stages of each parent and this should, therefore, be earlier maturing than either parent.

In tropical countries the available results of investigations on vernalisation while it has advanced our knowledge would appear to indicate its limited usefulness except when used as an expedient to escape natural phenomena which make crop production risky. So far as its utility in inducing earliness is concerned, particularly in rice, it may be said there is a wide range of cultivated forms already available and it should not be difficult to choose what one needs for a given set of conditions.

Work done on rice

(1) *Madras.* Seeds of a pure line of rice were vernalised [Parthasarathy, 1940] for three weeks in darkness or in light maintaining the temperature in either case between 10° and 20°C. Vernalisation in light was done by a continuous illumination with an electric lamp of 500 watts. The crop resulting from these seeds did not show any peculiarity except that the flowering duration of the plant from the seed vernalised in darkness was significantly earlier than that of control by five days. It was observed that both diastase and catalase increased during the vernalisation process, the treatment in light causing greater increase than that in darkness.

(2) *Bihar.* Two temperatures 0-2°C. and 10-12°C. for 4, 8, 12, 16 and 20 days were used on germinating seeds kept in darkness, and it was found that the higher temperature treatment induced greater height and higher yields, but no earliness of flowering [Alam, 1939]. Field scale tests with seeds vernalised (a) for twenty days at 10-12°C and (b) for 12 days at 0-2°c. were conducted for two years. While in one year the results were inconclusive, in the other, treatment (a) gave a significantly higher yield over control with no reduction in duration.

(3) *Bengal.* Hedayetullah and Sen [1941] conducted a small field scale trial with vernalised seed of a short duration *aus* variety. The seeds were germinated at 29.5°C. with 50-60 per cent of water calculated on the dry weight of the seed. There were six treatments with three temperatures, viz. 0°C., 11°C., and 29°C. and two exposures of ten and fifteen days at each temperature. The results showed that seed vernalised at about 29.5°C. for 15 days was significantly earlier in flowering by 12 days and did not also suffer in yield.

(4) *United Provinces.* Three groups of seed including control, germinated in open condition and in darkness were vernalised for two periods of 6 and 12 days under two temperatures of 25° and 30°C. The treated seeds were grown in replicated experiments for two seasons and data collected on plant height, weight of grain, number of tillers, length of panicle and days taken to flower. The results did not show any significant differences among the treatments.

(5) *Other places.* Haigh [1934 and 1935] has reported results of his experiments on vernalisation in rice conducted in Ceylon. The pretreatment of the seed in one experiment consisted of soaking the seed for 24 hours and then vernalising for six, ten and fifteen days respectively at 25°C. and comparing them against a control which was sown dry. The crop from the vernalised seeds as compared to that from the dry seeds, showed small but significant reduction in life period as was observed in Coimbatore. But when this was compared against the cultivator's method no significant differences in life period were observable. It is usual with the Ceylonese farmer to keep the soaked seed at room temperature which is somewhere about 30°C. for six days. As a matter of fact seed vernalised for fifteen days produced some adverse effects. In a second experiment, seed

was vernalised only for six days at increasing temperatures of 25°, 30° and 35°C., and it was found that there was only a slight decrease in the duration at the higher temperature as compared with the cultivator's method, but the difference had no practical value. In new South Wales, Ossewaarde [1934] conducted experiments on vernalisation in which seeds of rice were maintained for two weeks and five weeks after germination at 3° to 5°C. When the crops from these were compared, it was found that in both of them the growth and tillering were more advanced and the flowering was earlier by four to seven days. The grain yield was higher only in the two-week treatment, and it was lower in the five-week treatment. Skripcinskii [1940] obtained a distinct response with one of the Indian varieties at Krasnodar, U.S.S.R. This variety flowered 10 days earlier after vernalisation at 7°C. and 8 days earlier after vernalisation at 15°C. than the control plants grown in short day.

Tropical and subtropical plants including rice are classed as short day plants and thermophytes. In several of the experiments the temperatures given are perhaps not the optimum. Rice requires higher temperatures consistent with keeping alive the seedlings, and also short day illuminations for the developmental stages before reproduction. A number of workers has demonstrated the influence of high temperature in accelerating flowering in a number of rice varieties. There are also instances in which varieties grown on the plains when moved to altitudes of 3 to 4 thousand feet above sea level become late maturing chiefly due to the lower temperatures at the high altitudes. Giving higher temperature treatment to the germinated rice seed should not present any practical difficulty unlike in maize or soyabean for, the resulting seedling can be directly transplanted in the fields. It may also be possible to control moisture and prevent the germinated seed growing into a seedling. There is, however, some difficulty to keep the seed free from moulds and fungus attacks. The technique has yet to be perfected for rice to be of any practical value.

It has yet to be decided at what stage the light treatment should be given to the seedlings whether in continuation with the temperature treatment or after the seedlings have grown for some time. Further investigations may have to be taken up on the following aspects :

(1) the effect of treatment with high and low temperatures ;
(2) supplementing pre-sowing treatments with further post-sowing photo stages ; and
(3) giving the post-sowing photo stages as pre-sowing treatments.

Photoperiodism

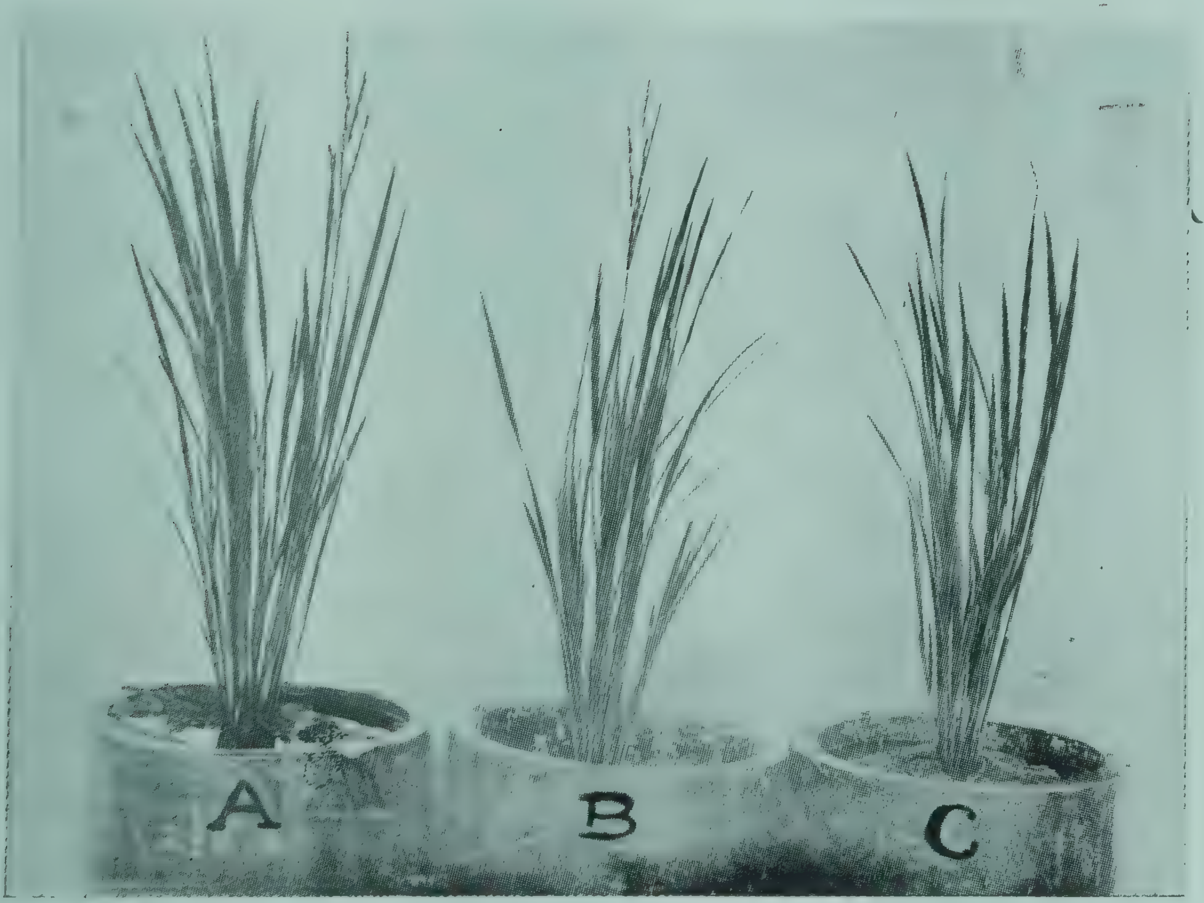
Connected with the theory of vernalisation is the influence of light on growth and development of rice. If vernalisation is defined as treatment in early stages of growth which shortens the vegetative phase, one may speak of vernalisation by short days. The 'length of day' factor has been found to be complex and seems to consist of a number of units all of which affect the plant's activities. It has been suggested that the length of day brings about adjustments in the amount of water passing through the tissues and operates by affecting the sugar-starch relation. Flowering plants may be divided into the following types according to their reaction to exposure to light : (i) indifferent or ever blooming plants which flower equally well irrespective of different exposures of light; (ii) short day plants which hasten flowering with shortening of the normal light period; (iii) long day plants in which the flowering is accelerated by relatively long exposures to light; (iv) intermediate types and (v) types that do not flower at all on longer exposure.

The response to different exposures of light in the growth and flowering in rice has been studied largely in Japan and by a few workers in India of whom the investigations of Dr. Sircar may be specially mentioned.

According to Sircar [1942 and 1948] rices are divided into two classes, summer and winter rices, the terms denoting the seasons in which they bloom. These two differ with regard to their requirements of photoperiods. While short days are essential for the flowering of winter rices, they delay flowering in summer rices. On the basis of this finding Sircar has developed a technique of vernalising rice seedlings by the application of short days for varying periods. In one of the winter rices, *Bashamanik*, the seedlings were exposed to continuous short days of 8 hours, 8 a.m. to 4 p.m., and this resulted in a considerable reduction of age. He also found that the short day treatment while accelerating growth also increased the number of ear bearing tillers and consequently yield. In another winter rice, *Rupsail* which was given short day treatment for six weeks, the flowering duration was reduced even more than in the case of *Bashamanik*, and in this case, the vegetative growth itself was affected. He also noted that while such reduction in duration was observable in the main shoot only, the flowering of the first and second tiller got delayed, and the later tillers flowered almost at the same time as in the control. Based on these results he concluded (1) vernalisation response was a varietal character; (2) the vernalising effect of short days was of a quantitative nature as the degree of earliness increased with the duration of the experiment; (3) all winter rices were short day plants; (4) there was probably a flower forming hormone synthesised in the layers and translocated to the growing point and to the buds already formed during the period of treatment which makes the developing shoots to flower earlier and (5) tillers developing from buds formed later did not flower early. There are however certain points that need confirmation. It would probably have been better if the two varieties *Bashamanik* and *Rupsail* were both given the same treatment, continuous short days and short days for six weeks only. It remains to be seen what the effect of short days would be on summer rices. The results of Sircar's experiment on *Rupsail* would appear to confirm the individuality of tillers in rice observed in Coimbatore studies.

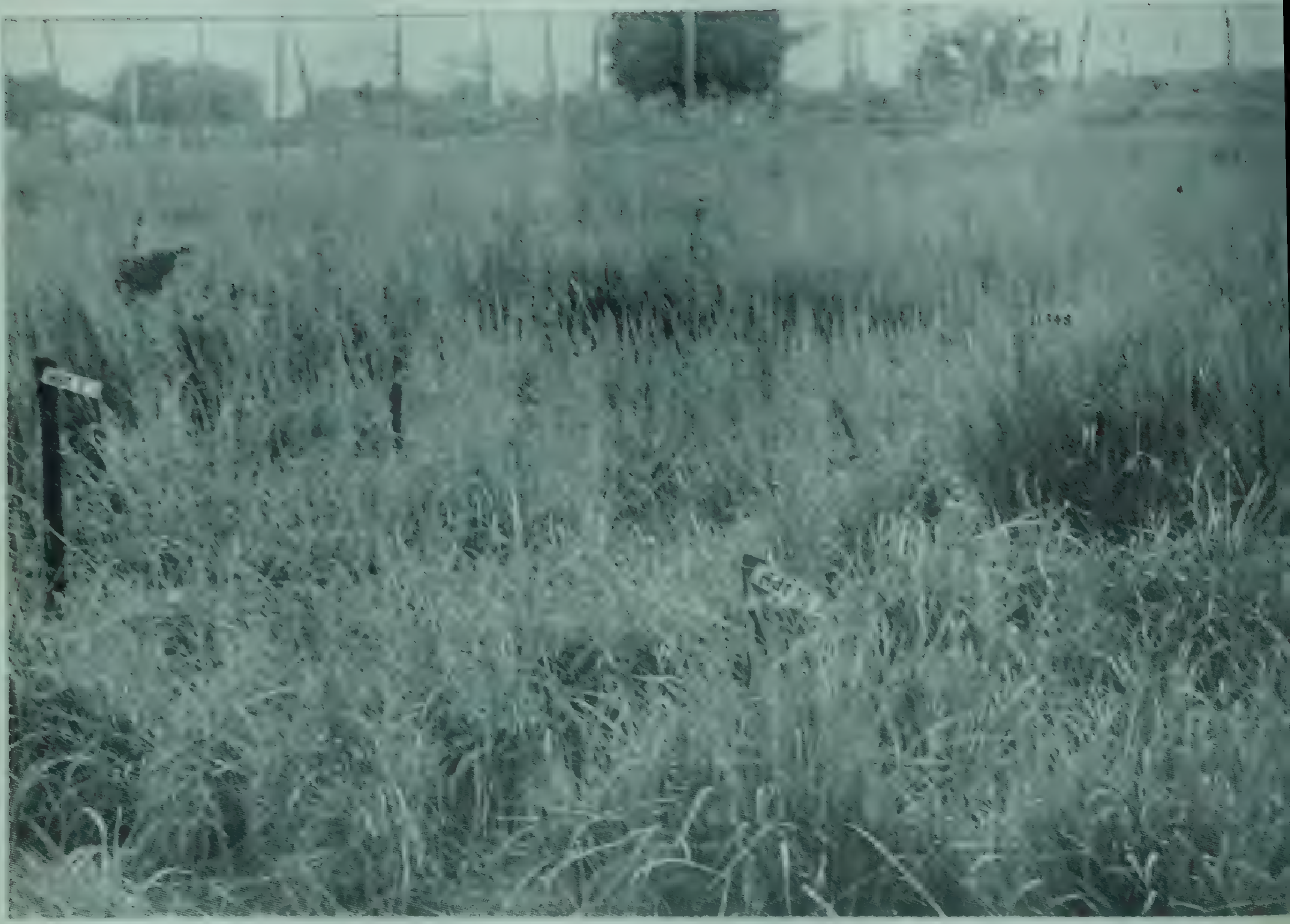
It has been the experience of rice workers that forms introduced from the sub-tropical regions into the tropics with relatively short day conditions produce rather small plants flowering very early. Similarly when forms from the tropics are taken to the sub-tropical regions they become vary late maturing and often fail to head. These results are explained as due to differences in day lengths between the two regions. But the prevailing temperatures in the two regions must also be partly responsible for this behaviour, as higher temperature hastens flowering while lower temperature delays it. India itself lies between 8-37°N latitudes and naturally there is some difference in day lengths between North and South India. There are several instances in which varieties became slightly earlier or slightly later when moved from North to South India and these results should

PLATE XXVII



Exposing plants to light

Pots A and B received short day and flowered 1st week August.
Pot C, Control. Not flowered yet. Normal flowering end of October.



Resistant and susceptible types to piricularia
Adt. 1, 2 and 10 (front) susceptible while hybrid culture 11348 (back) is resista

also be explainable on the basis of differences in day lengths. Differences in flowering period have also been observed when the same variety was sown in different seasons at the same place [Ramiah 1933]. The differences in day lengths must be extremely small in this case, but according to Russian workers, even these small differences are considered enough to account for the differences in flowering periods. Examination of all the relevant data available would however seem to indicate that the small differences in day lengths observed in different parts of the year in South India might not be enough to account for the results obtained. It has to be noted that only long duration rices, corresponding to Sircar's winter rices are affected by different seedling dates, and the short duration rices do not change their life period irrespective of when they are grown. In fact, there are rices in different parts of India, which irrespective of the season in which they are planted, take the same time to mature.

Alam (1936) subjected rice plants transplanted in pots to different illuminations, thirty days after transplanting; and the results obtained in the several treatments are summarised in Table XII.

TABLE XII

Results of photoperiodic studies in Bihar

Treatment	Flowering time	Average weight of shoot (gm.)	Remarks
(1) **Sun light for 10 days and then constant light for 40 days**	**December 9**	46·0	Flowering delayed
(2) Sun light for 20 days and then constant light for 30 days.	November 16-20	76·7	..
(3) Sun light for 30 days and then constant light for 20 days.	November 26 to December 5	103·6	Growth fair
(4) **Sun light for 40 days and then constant light for 10 days**	October 23-28	113·2	No change in growth or flowering
(5) **Receiving usual sun light** ..	**October 22-28**	**127·1**	..

(Constant light was provided by Petromax light)-

In another set of pots, the constant light treatment was given first and then the sun light for similar periods, as in the first set of pots. The results were more or less similar, the treatment with longer exposure to constant light suffering most. The results show that by shortening the day suitably, rice plants may be made to flower early and by lengthening the period the flowering may be delayed (Plate XXVII).

Rhind [1937] subjecting three pure lines of long duration varieties grown in Burma to short periods of light, eight to ten hours in duration, succeeded in reducing the life period by forty days. The control in this case had 11 to 13 hours of day light. There were no differences between the eight hour and ten hour treatment.

In Japan several workers have studied the photoperiodicity of rice. Yoshi [1927] has recorded that late rices alone behaved as though they belonged to short day class while early ones were indifferent to the regulation of the light period. Hara [1930] working with Japanese rices recorded a suitable photoperiod of 8 to 10 hours when plants flowered very early. Late varieties and high altitude types were more susceptible to short day treatment. Kondo *et al.* [1932] have shown that exposure of 8 to 12 hours during the seedling stage affected the flowering. To hasten the appearance of the panicle, they record that a short illumination of 5 hours must be applied as early as possible during the growth of the plants. When plants were subject to continuous illumination day and night, they found that the plants did not produce panicles for a period of 3 years, but at the end of the period they flowered and set grain as usual. Tabata *et al.* [1932] found that under short periods of illuminations, early and late plants eared approximately at the same time and it was only with increasing illumination periods were the differences between early and late varieties manifest. Pan [1936] has shown that when rice plants were subject to exposure of light for 6, 9 and 12 hours there was a marked decrease in tillering; with decreasing lengths of exposure the height of plants increased but the period of maturity was hastened. The effect was seen to be much greater with late maturing varieties. Noguchi [1942] has recorded that Fuke succeeded in saving a year in the breeding of low land rices by exposing F_4 hybrids to electric light and short day illumination, and that vernalisation has been successfully used by Kakizaki and Kido in hastening breeding time in low land rice by exposing the grains to temperature of 37°C.

Rajbov [1942] records some interesting experiments on rice plants. Rice plants growing at the Bezencuk station were subjected to a ten hour day for 20 days. Different varieties reacted differently, the time of panicle emergence being hastened in some by periods varying from 3 to 47 days and delayed in others by 5 to 20 days. The latter group consisted mainly of early varieties, the late varieties being all accelerated by the treatment. Some of the varieties when treated emerged sooner (3-7 days) than the local standard under similar treatment, which showed that in respect of phases other than the light phase, they were better adapted to Bezenuck conditions. By crossing such forms with those that did not react to reduced day length (with short photo stage) it was possible to produce forms exceeding in earliness both the parents and the earliest standard variety. Thus in the F_1 and F_2 of the cross between short photo stage parent and a rainfed type, forms were found which emerged 6 to 8 days before standard, 5-6 days before the earlier parent and 10 to 14 days before the late parent. In fact the Russian workers think that even the results of inheritance studies in flowering duration reported by Ramiah could be explained on the basis of photo stages.

11. Relation of size of seed and crop resulting from it

One of the problems which has not yet been solved completely is the influence of weight of seed on the vigour and yield of the resulting plant. It is obvious that good seed is the foundation of good farming but how far the use of specially picked large seed in a pure line will improve the yield and will pay the labour involved in such separation is a matter which has not been proved beyond doubt. The size of seed is determined by the climate and edaphic factors acting on the parent and the position of the seed in the inflorescence. Though the effect of large and small seed on the resulting crop has been compared, no critical investigation has been carried out on the subject whether large seed comes from large and more prolific plants or whether small low yielding plants produce a larger percentage of heavy seed. Also the relative values of small seed from small and large plants are questions which require special study.

A large number of investigations has been carried out in cereals on weight of seed and plants resulting from the same, chief of which are those of Zavitzy [quoted by Kidd and West 1918], Percival [1921], Holfman [1923], Kisselbach [1924], Haylor [1928], Firky [1937] and Mukhin [1942]. While according to Percival weight of seed sown had no effect in wheat so long as the soil was in a good condition of fertility, the evidence available appears to be in favour of heavy seed. There has not been much study on this aspect in rice but the universal practice of grading the seed by the salt water method adopted by the farmers in Japan and Formosa appears to have a justification when reviewed in the light of the evidence from other cereals. It is stated that the farmers also reserve the produce from upper third of the panicle for seed purposes. But experiments in Java and the Philippines have not shown any advantage in separating the heavy seed from the light by the salt water method. Hector [1913] has reported that in *aus* varieties in Bengal which contain generally 25 per cent of light and shrivelled grains, the selection of seed by the specific gravity method had yielded results of value.

An experiment was carried out on this aspect at Coimbatore, in two pure lines, Co. 4 (long duration variety) and Co. 10 (a short duration variety). A small sample of seed from each was graded into three groups light, medium and heavy, based on the weights of individual grains and 100 plants in each group were planted in randomised and replicated trials with regular spacings. It was found, that (1) the heavier seed in both the varieties germinated earlier and seedlings showed greater vigour, but in the long duration variety the initial advantage was not maintained in the later stages; (2) there was no difference, however, between the mean weights of individual grain in the produce of the different treatments and (3) the yield was significantly high from the heavy seeds in the short duration variety, Co. 10, but in the case of the long duration variety, Co. 4 there were no differences in yields among the three grades. A replicated trial with larger plots was conducted later and the results given below confirmed the above findings.

Yields of graded seed in percentage (*variety Co.* 10)

	Heavy seed	Light seed	Ungraded seed	Cr. difference
1936-37	102·2	94·4	100	3·7
1937-38	102·4	93·1	100	3·8

The above results would show definitely the advantage of heavy seed or rather the elimination of light seed for sowing purposes particularly in short duration varieties. The difference mainly consists in the greater early vigour imparted to the seedlings from the heavy seed. Though the early difference is present even in the long duration varieties, it disappears after some time. That the planting of well grown and strong seedlings is better than planting thin and weak seedlings is well recognised. This is apparent from the cultivator generally choosing the best available land for raising nurseries, and applying the limited quantity of manure available to the seed bed rather than to the transplant field. Sometimes healthy and vigorous seedlings can be raised by adjusting the seed rate in the nursery. By sowing the seed beds thin, the seedlings have more space to develop and are strong. However uniformly one may try to sow the seed in the nursery, there is bound to be difference in the type of seedlings obtained from the same bed. Along the edges and where the seedlings are not crowded, they are stronger and thicker than in the crowded portion of the seed bed. In one of the early experiments at the Paddy Breeding Station, Coimbatore, the strong seedlings were found to give a higher yield than the weak seedlings, both obtained from the same seed-bed. It has always been the practice at this station to take the normal seedlings from the centre of the seed bed for planting in experiments involving comparisons of tillering, yield, etc.

12. HETEROSIS

Apart from the specific action of genes governing size characters in crosses, it is observed that increased vigour of growth and production usually accompanies hybridisation both in animals and plants although it is by no means a universal phenomenon. This vigour which is exhibited by the hybrids is called hybrid vigour or *heterosis*. The study of this phenommenon appears to be necessary in all plant breeding work to differentiate the effects of dominance from effects due to heterosis. As East [1936] has put it, the problem of heterosis is the problem of interitance of quantitative characters. Vigour is associated with increased manifestation in different characters, viz. height of plants, earliness, greater vegetative growth and finally yield.

The existence of heterosis has been exploited by horticulturists and stock breeders for quite a long time for improving their material. Even in plants reproduced from seeds, the phenomenon of hybrid vigour is made use of in maize, egg plant, tomato, etc. by growing the first hybrids on a commercial scale.

Heterosis has been explained by the hypothesis of a number of dominant genes which are brought together in hybrids and the greater the number of such genes, the greater the manifestation of hybrid vigour. Ashby [1930 and 1932] was the first to study the physiological aspect of hybrid vigour in maize and tomato and he found that seeds which produced F_1 hybrids showing heterosis are heavier than seeds of the parent. He maintained that genes controlled plant size through determining the initial size of the primordia and explained his data on the basis of principal and interest; the greater the principal (primordial size) the greater the total accrued interest (plant size) while the rate of interest (rate of growth) was constant for the parents as well as for F_1s. This hypothesis claimed that the embryo should be sufficiently large in the cross seed to continue its efficiency in producing heterosis in later stages of growth which, in many cases, was not found to be true. But the implications of Ashby's work were of such weight that intensive studies had been initiated on this aspect of embryo size. Of particular interest are the experiments of Grekov [1942]. To increase the nutrition of the embryo the endosperm of another grain of the same variety was stuck on the cut surface of the grain which resulted in higher yield and earlier ripening.

The different degrees of heterosis are attributed to particular genes or perhaps to particular combinations of a small number of genes having special effects. As the study of heterosis was connected with size inheritance, certain precautions in the technique of experimental layout to ensure minimum disturbance due to environment would appear necessary. In the reported studies on heterosis in rice however, the correct technique of layout to even out soil and other environmental differences has not been followed.

Hybrid vigour is estimated by different workers in different ways, (1) by comparing the F_1 value against the mean of the two parents; (2) by comparing the F_1 value against the parent having the higher value and (3) by comparing the mean of the reciprocal F_1s against the mean of two parents. The last method is the one recommended by Fisher *et al.* [1932] provided, extraneous environmental and other non-genetic effects have been controlled or eliminated, and the truly genetic differences only are compared.

Results of studies on hybrid vigour in rice have been reported by a number of workers in India. Sethi [1937] studied four crosses comparing the parents and F_1s (including reciprocals) in one year and the parents and the F_2s in the next, the latter in a replicated experiment. Several characters namely, height, length of panicle, weight of grain per plant, number of tillers, duration up to flowering, sterility, etc. were studied. The results showed that in the F_1 hybrids, the 'vigour' was not pronounced in any of the characters studied, the mean of the F_1 values being not greater than the mean of the two parents. In the F_2s also a similar situation prevailed. In the F_1 comparisons, height showed a 10 per cent increase only in one cross and the values for the other characters were the same or even a little lower than the parental means. Kadam [1937 b] studied five crosses together with their parents in respect to height of plant, number of culms per plant, length of panicle, yield and weight of whole plant. The number of F_1s studied was small and there was again no definite evidence of heterosis in many of the characters. In two crosses however, the mean yield of the F_1 plants was significantly higher than that of the higher yielding parent.

Ramiah [1935] records that from studies made by him on crosses in rice for a number of years, he found the first generation hybrids showed hybrid vigour by greater tiller production and earlier flowering than the parents, and that the expression of such vigour, however, varied with different crosses. Four sets of crosses between varieties with different sizes of grain were studied by Ramiah and Ramaswamy [1941] specially from the point of relationship of grain and embryo size to hybrid vigour. From an examination of the endosperm of rice grains with sizes varying from 7.9 to 27.7 gm. it was found that the weight of the embryo and size of grain were highly correlated ($r = +0.9$). To avoid mechanical operation of emasculation and pollination having differential effects on the selfed and crossed seed, they obtained selfed seed by artificial emasculation and pollination from the same plant. Since tillering was the most inmportant developmental phase and formed a direct index of vigour, the authors made a periodical count of the number of tillers per plant for the whole population of parents and F_1 which consisted of not less than 60 plants in each cross.

The hybrid vigour in three of the crosses was confined mostly to the number of tillers per plant and hence also to the final yield. One of the crosses, T.6 × T.115, involved the largest difference in grain size between the parents, the size of the embryo was the same as that of the selfed seed when the larger grained type was used as the female and was significantly greater in weight than the female parent in the reciprocal cross. Still the reciprocal F_1s showed marked hybrid vigour as compared to the parents in tillering, final number of ears per plant, flowering duration and panicle length. It was also seen that the reciprocal F_1s did not exhibit any significant differences between themselves, and in number of ears, both the F_1s showed marked vigour over the parental average. This fact would, therefore, suggest that neither the embryo size nor the quantity of endosperm reserve material can account for the manifestation of hybrid vigour. The weight of F_1 grain in the reciprocal cross resembled the shorter grained parent because of the dominance of short grain. Even when hybrid vigour was present, the relative growth rates of the F_1s and the parents were nearly the same though the initial differences between F_1 and parents tended to either increase or decrease at later stages of development. This is in accordance with Ashby's finding that the hybrid does not differ from its more vigorous parent in relative growth rate.

It is recorded by Ramiah that observations made on 500 F_1 plants involving 26 sets of crosses, manifestation of hybrid vigour was present only in a few cases. Six of the 26 crosses showed heterosis for earliness, only one for the number of tillers per plant and four for plant height. Thus it may be said heterosis was not of great consequence in rice. Jones [1926] studying a small population of the first generation hybrids in four crosses has reported that there was some evidence of hybrid vigour with regard to height when the F_1 values were compared with the mean of the parents, but there was no evidence with regard to length of ear, number of culms per plant, and yield.

However, Idsumi's studies [1937] in rice crosses showed a greater evidence of hybrid vigour. He studied exhaustively the first generation hybrids from seventy nine crosses which included sixty one varieties. He found heterosis in plant height, weight of stems, ear length and tillering. In 80 per cent of the cases the F_1 exceeded the average of the parents, and in 50 per cent it exceeded the higher parent. There was simultaneous expression of vigour in all the characters and the similarity or otherwise of the characters in the parents had no marked influence on the occurrence of heterosis. He found that heterosis was more pronounced in crosses within the *indica* group than in crosses between *indica* and *japonica* groups which is not what one would expect from theoretical considerations.

Capinpin and Punyasingh [1938] studying the F_1s of nine crosses between Siamese rice varieties found that there was marked heterosis in height and panicle length in five crosses, and in yield in two F_1s. No marked heterosis was observed either in the number of culms per plant or in grain size.

An interesting observation may, however, be recorded from the results obtained by Ramiah in cross T.6 × T.115. The higher values of most of the characters in the F_1 over those for the reciprocal followed the higher initial advantage which the particular F had by way of higher embryo weight. Mention must, however, be made that the embryo in cereals, as in rice, represents less than a tenth of the weight of seed, a large portion of which being represented by endosperm. The endosperm in cereals is more of maternal tissue than of hybrid origin and may not have as much influence in heterosis as in some non-endospermic plants.

13. DISEASES OF RICE AND BREEDING FOR DISEASE RESISTANCE

General

Disease, as popularly understood, is an ill-balanced condition in the physiological activities of the organism, and it may be caused by external agencies like pests and pathogens or may be a direct result of failure or decrease in vigour of the normal functions of the several organs. The symptoms of disease may sometimes appear alike, whether it is caused by a specific organism or is due to some physiological deficiency. While some of the diseases particularly those that are seed borne can be controlled by means of special seed treatment, treatments for other diseases are sometimes impracticable over large areas. Again the control measures have to be repeated every year for an effective check and sometimes will have to be followed up by preventive or prophylactic measures. In the case of some diseases, control measures entirely fail and in this event, the main hope for the successful growing of a crop appears to be through the development of disease resistant varieties by breeding methods. Breeding for disease resistance is assuming great importance in the plant breeding programmes of many countries.

That fungus diseases cause annually a heavy loss in the important food crops is well recognised. To take only two examples, it is estimated that smuts on *jowar (Andropogon sorghum)* in the Bombay Presidency cause an annual loss of a million rupees, and the wheat rusts in India about four crores of rupees. In countries like Britain, the United States of America and Canada, there are agencies like 'National Disease Surveys' which obtain and compile information regarding the range of plant diseases and crop losses due to such diseases. Such an organisation does not exist in India. Out of the sixty rice diseases which are listed by Stevens [1933] only some are considered to be of some importance in India. This does not mean that the rice crop in India is more free from diseases than in other countries, but it only means that very little has yet been done in India with regard to diseases. Some occur in a chronic form causing what would appear to be inequitable losses to individual growers but in the agregate are responsible for several thousand tons. There are other diseases which break out periodically in an epidemic form causing loss of crop to the extent of 50 to 80 per cent of the crop. It is the control of this later category of diseases that holds out promise of substantial increase in the production of rice in the country. The Indian Council of Agricultural Research has sanctioned schemes in provinces for undertaking extensive mycological investigations on some of the diseases of rice belonging to the latter category.

The breeding of resistant forms is beset with a number of practical difficulties. As is generally experienced, disease resistant forms existing in nature are not always the most favourable from an agricultural point of view. The grower lays stress on such characters as duration and quality of produce, and more than anything else, on yield. For example, in rice, the Tanjore cultivator in Madras prefers to grow the varieties, *Korangu samba* and *Nellore samba,* most susceptible to *Piricularia,* because of their characteristic greater yields though other varieties are available which are resistant to the disease. He would rather gamble on the possibility of the disease not appearing in an epidemic form and grow the susceptible varieties. The success of breeding disease resistant forms, however, depends upon how far the desirable agronomic qualites are associated with disease resistance. The degree to which the defensive mechanism of the resistant variety expresses itself in inheritance has also an important bearing in the success of the attempts to breed superior resistant varieties.

The general question of breeding for disease resistance in crop plants can be discussed under various aspects such as parasite-host relationship, effect of environment on such relationship, nature of resistance in the host, physiological races of the parasite, genetics of resistance, tecnnique of breeding for resistance, etc. The most important requirement in every programme will, however, be the development of a suitable technique for creating an environment in which the pathogen has the optimum conditions for development so as to provide a reliable index of the natural resistance of plants under study.

Diseases in rice

(1) *Blast*; (*Piricularia oryzae*), Briosi and Cavara.

General. Of the diseases of rice, the most serious one is *Piricularia* known as rice ' blast '. The disease caused by the fungus, *Piricularia oryzae,* attacks almost every portion of the plant, its first appearance being indicated in the leaves in the form of tiny brown spots developing into oval or elongated lesions. In the culms, the attack is conspicuous at the nodes, the neck and branches of the ear. The extent of the damage depends upon the stage at which the plant is attacked. The fungus is propagated through its spores and mycelial threads, and it has been found in Japan that the spores can live in dry condition for a period of seven to eight months, sufficiently long to bridge over from one season to another. The spread of the fungus spores takes place through the agency of wind and rain. It has been found by Abe [1935] that no infection of rice seedlings could take place in relative humidity lower than 90 per cent. The fungus survives in rice soil up to 13 months, and once it sets its hold on the crop, it spreads like wild fire over extensive stretches so that the problem of controlling the disease becomes difficult. Though the presence of disease can be made out easily, the extent of damage becomes apparent only when the crop is harvested. The attacked ears look like normal ones but when the crop is threshed the ears are found to contain only unfilled or partially filled spikelets contributing mainly to chaff. The ears becoming largely sterile and chaffy is the characsteristic symptom of the disease.

This disease is known to occur in all the rice growing countries of the world and it was first recognised in Japan even two hundred years ago. Breeding for *Piricularia* resistance has been one of the important items in the rice breeding programme of the country. Its existance in India was however, not recognised until 1918 when it appeared in an epidemic form in some portions of the Tanjore district in South India causing more than 60 per cent loss in some localities. McRae [1918] had, studied the disease very thoroughly and observed great variations in the occurrence of the disease among different cultivated varieties. The studies continued by Sundararaman [1922] and Thomas [1930] on several varieties of rice had shown that certain strains of the Paddy Specialist, Coimbatore, for example, Co. 4 and Geb. 24 were less susceptible to *Piricularia* than others, and it was this knowledge that had formed the basis for a programme of breeding resistant varieties. Later work has shown that Co. 4 is 100 per cent resistant to the disease. Two varieties *Thabouri* and *Zdulake* are reported to be resistant to *Piricularia* in Assam [Anonymous, 1940]. Two Italian varieties, American 1600 and Benboch are found to resist this disease more than the local varieties in Mysore. Though the disease is reported to occur in Bengal, Bihar, Assam and Mysore, it does not seem to be very severe in these areas as in portions of Madras where some of the high yielding and popular varieties are particularly susceptible to this disease causing enormous losses. The work of Ramiah and Ramaswamy [1936] in breeding *Piricularia* resistant types in Madras is dealt with below. This was undertaken with the co-operation of the Mycologist at Coimbatore.

Hybridisation. One of the varieties called *Korangusamba* in the Tanjore delta which is a high yielding and a popular variety is subject to the disease in some years. Another major variety in the Nellore tract called *Mologolukulu,* the most popular table rice in the southern districts of the Province, is also subject to this disease. Crosses were made between *Korangusamba* on one side and Geb. 24 and Co. 4 on the other, the latter being the two resistant parents. The first cross was made as early as 1926 and the second, three years later. The F_1s were largely chaffy and showed the characteristic symptoms of the disease though in a much milder form than the susceptible parent. Sixteen F_2 families comprising of a population of 33,000 plants were raised and studied regarding several morphological characters like the angle of the boot leaf, hairiness of the leaf, degree of exsertion of the panicle, etc. together with the degree of disease incidence as evidenced by the appearance of diseased spots in the leaf, stem and neck of the panicle. The results did not reveal any definite correlation between these morphological characters and disease incidence. The flowering range of the F_2 population showed a peculiarity in that none of the individuals was as late as *Korangusamba,* the later of the two parents.

Inheritance studies. It may be mentioned that the degree of incidence of the disease showed differences in the same family when grown in different fields and there was also marked variation in the occurrence of the disease from season to season due probably to difference in climatic factor. Classifying all the individuals which showed traces of the disease in any part of the plant as diseased and the rest as disease free, the results obtained were :

Cross	F_1	F_2 frequencies	
		Diseased	Disease free
Korangu samba X Geb. 24	Intermediate ..	248	63
Korangu samba X Co. 4	Disease free ..	161	311

From the nature of resistance in F_1s and the ratios obtained in the F_2 generations, it would seem that the nature of inheritance was different in the two crosses. Though it was not possible to pursue the inheritance studies beyond the F_3 stage, the observation on the incidence of the disease led the authors to conclude that resistance might be a simple recessive in the first cross, for in the F_3 generation plants selected for resistance all bred true. A similar result was also obtained in this cross studied at Aduturai. In the second cross, the inheritance was somewhat more complicated and the obtaining of disease free selections breeding pure has taken somewhat longer time. Sasakai [1922] found that immunity was dominant over susceptibility in F_2 which gave a 3 : 1 ratio of immune to susceptible. In the F_3 generation the author could not, however, distinguish immune homozygotes from immune heterozygotes and susceptible homozygotes. Although the number of apparently immune individuals in F_2 amounted to seventyfive per cent of the total, yet it varied between fiftyfive and ninety per cent in F_3, and by plotting the curve of variability the author concluded that the variation was only a simple fluctuation. Nakatomi [1926] found that resistance to *Piricularia* in rice was due to two complementary genes giving a 9 : 7 ratio of resistance to susceptibility. The genes for *Piricularia* resistance are designated P_{ia} and P_{ib}.

Evolution of blast resistance strains. A significant fact that was observed in the F_2 generation of the crosses studied in Madras was that the susceptibility was more prominent in the plants which resembled the susceptible parent in other morphological characters, as for example, the nature of heading. Every family in the F_3 and subsequent generations was grown interspaced with the susceptible variety in an area which was always subject to attack of the disease though its virulence varied from year to year, and also spraying with spore suspensions at different stages of the crop. This had created favourable conditions for the disease to develop and the progenies were always exposed to infection and their resistance when present was, therefore, due more to genetic constitution. By gradual selection and elimination, 40 F_5 families apparently homozygous for resistance were put under yield trials and by 1937 the best two strains Co. 15 and Co. 16 were released for general distribution as an interim measure. After five years of cultivation in several places of the province it has been reported that these strains Co. 15 and 16, are exhibiting slight degrees of infection in different years and in different places and it was, therefore, felt that the strains might not be homozygous completely for disease resistance. The failure to obtain progenies like *Korangu samba* in other characters along with *Piricularia* resistance was however an important point in this case. The other cross Co. 4×*korangu samba* had proved more hopeful and at the present moment a range of new varieties resistant to the disease even under the most adverse conditions and giving satisfactory yields has been obtained. Two of these, named Co. 25 and Co. 26 are now being multiplied for large scale distribution. This is an excellent example of a successful cooperative effort between the Paddy Specialist and the Mycologist at Coimbatore.

The other variety which is subject to this disease is *Nellore samba* or *Mologolukulu* and work on this variety is concentrated at the Rice Research Station, Butchireddipalem. Here by making selections in the commercial samples of this variety and subjecting them to infection by surrounding them all round with the susceptible variety and growing them late in the season when the disease always makes its appearance, a few strains which are free from disease constantly for some years have been isolated and the work is still in progress.

Physiological forms of blast fungus. Notwithstanding progress that has been made in the evolution of resistant strains which are eagerly sought after by the cultivators, there is still lack of fundamental knowledge in India about the disease producing organism and the peculiarities of the resistant parents by which the resistance is being secured. In Japan Suzuki [1935] had isolated several forms physiologically and pathoenically different. Nine physiological forms of *Piricularia* were distinguishable [Yushika *et al.*, 1936] whose conidia differed in their size as well as apex shape. Inoue [1939] has identified twentyone strains of the *P. oryza* fungus which possessed varying degrees of pathogenicity as evidenced by their differing capacity to decompose cellulose. In India forms of *Piricularia* are found to attack other cereals such as *ragi* (*Elusine coracana*) and *tenai* (*Setaria italica*) and two grasses *Digitaria marginata* and *Panicum repens*. While earlier work in Madras had shown that *Piricularia* from the two cereals mentioned above did not attack rice, more recent work has shown that the fungus isolated from *Panicum repens* is pathogenic to rice. Whether different forms exist in the *Piricularia* organism attacking rice itself is not known. Even if such physiological forms exist it should not frighten the breeder. Experience with the breeding of disease resistant superior forms in other crops has shown that the physiological forms fall generally into groups so that a type resistant to one form has found to be equally resistant to a number of other forms also.

Atmospheric conditions and disease incidence. As has already been shown the disease is more epidemic in nature and it is, therefore, obvious that there is some intimate connection between seasonal factors and disease incidence. It has not been possible to definitly establish the nature of this association. Observations on the disease during several years in some of the Agricultural Stations in the Madras province have led to the belief that the distribution of rainfall especially at the time of flowering of the crop has a great influence, heavier rainfall up to the flowering stage and bright weather later, favouring a heavy attack. That resistant varieties in one area sometimes become susceptible in certain other localities, has also been observed. Geb. 24 which has been found to be resistant to *Piricularia* to a high degree in most of the places in the Madras Presidency was affected in Coorg where there is more rain and higher humidity when the crop approaches flowering stage. In Italy, it has been stated that rice varieties have to be constantly replaced as they lose their resistance to blast in course of time.

Internal structure and blast resistance. Little is known at least in India regarding resistance and cellular structure of the host on the one hand and the method of attack of the organism on the other. Thomas [*loc. cit.*] believes that an erect flag leaf, a short neck and a compact panicle and an abundantly hairy ligule are some factors associated with *Piricularia* incidence, while a greater frequency of vascular bundles and a higher distribution of sclerenchymatous tissues were associated with *Piricularia* resistance. These associations are at best only indications which might be useful in selecting from cross progenies. Nagai and Imamura [1931] have stated that the greater the number of stomata in the neck of the panicle, the more susceptible the variety was, but this applied only to the case of the *japonica* races and the observation did not hold with regard to *indica* types. As penetration of the fungus is usually through cuticular infection, Suzuki [1934] finds a relationship between resistance and the thickness of the outer walls and of the silicated outermost layer of the epidermal cell; greater resistance was observed by him when soluble silica was applied to the soil under flood conditions. Environmental conditions such as heavy manuring with nitrogenous fertilisers, soil acidity, etc. are known to predispose a variety to *Piricularia.* It has been found in Madras that while the newly bred resistant varieties remain resistant even when large quantities of nitrogenous manures are applied, some of the varieties tolerant to the disease break down when the quantity of nitrogen applied exceeds 20-25 lb. per acre. Restricted water supply did not induce greater resistance than copious supply under Coimbatore conditions as was found by Suzuki in Japan. The reaction of the character of the host cells to *Piricularia* incidence has also not been fully understood. Preliminary determination of the *p*H values of the cell sap has shown that the cell sap of the resistant type, Co. 4 was slightly more acidic than that of the susceptible type but whether this is associated with the resistant property of the variety is not clear. More extensive studies in this direction appear necessary.

*(2) *Helminthosporium and sclerotium diseases of rice*

Two species of *Helminthosporium* attack rice : *Helminthosporium oryzae* Breda de Hann and *Helminthosporium sigmoideum* Cavara. The former is the more common parasite and co-distributed with its host. It causes much damage to the rice crop in Japan, China, the Philippines, Java, Indo-China, Burma, Ceylon, India and the Southern United States of America. The severity of the epiphytotic which it causes depends on the climatic conditions. In India, it probably causes damage all over the rice growing tracts, but it has been stated to be especially bad in Sind, Bihar, Bengal and Assam. In the delatic areas of the Godavary and the Kistna districts in S. India it is present in a mild or a severe form, depending on the prevailing climatic conditions. Sundaraman [*loc. cit.*] has reported that in 1918-19 it caused immense damage to the rice crop in these tracts. In 1942-43 it occurred in an epidemic form in Bengal.

The disease manifests itself in the form of spots on both the surface of the leaves, leaf sheathes, necks, nodes, glumes and even grains. The spots at first are minute with a brownish central area which later becomes smoky black on the production of conidiophores and conidia. The spots gradually increase in size and frequently coalesce. Entire leaves may wither and dry up presenting a yellowish appearance. If the attack is severe at the heading time, the grain within the glumes shrivel and become discoloured, or they may not be formed at all. If the ears are attacked in an early stage, they may fail to emerge out of the enclosing leaf sheath.

The fungus is disseminated through spores and resting mycelia borne on the leaves, petioles, etc. and is carried from season to season in the seed. Seedlings raised from infected seed are often subject to a seedling blight. Later, these diseased seedlings provide the inoculum for secondary infection. For controlling the primary attack in the seed bed, treating the seed with hot water at 54°C. for a short period is effective. Several seed-dressings have also been reported to be promising. In Sind, where the seedling blight is very destructive, 'Silver Jubillee', a newly bred variety of rice, is reported to be resistant to the disease.

---

*I am indebted to Dr. B. B. Mundkur of the Indian Agricultural Research Institute, New Delhi, for much of the information reported here.

Tullis [1940] studying the anatomy of the resistant and susceptible varieties of rice found that the leaves are characterised by papillate epidermis, motor cells, armed type of parenchyma cells and usually large intercellular spaces in the photosynthetic areas. The hyphae of *H. oryzae* grow intercellularly in these areas and intracellularly in the motor cells; bundle sheaths of resistant varieties are less readily penerated, the bundles presumbly interfering with the lateral spread. In the resistant varieties the invading fungus is hemmed in by the formation of deposits which accumulate in those intercellular spaces.

Nagai *et al.* [1931] report that resistance to *H. oryzae* was dominant in F_1 and a 3 : 1 segregation of resistant to susceptible was obtained in the F_2. Contrary to this finding, Adair [1941] has stated that the reaction to *H. oryzae* was controlled by several genes, resistance being recessive, and that factors for reaction to the disease assorted independently of the factors controlling morphological characters. In the Philippines, Reyes [1937] obtained a hybrid progeny which possessed a fairly high resistance to the disease from a cross between two susceptible varieties which probably confirmed that resistance was a polygenic character.

In spite of its great importance in India, *H. oryzae* has not received as much attention as it deserves. While the primary infection in the seed bed can be arrested by seed treatment, it is the secondary infection that is most destructive to the crop. It has been estimated that in 1942-43 when there was a severe epidemic of *H. oryzae* in Bengal, the loss of crop estimated at the research stations ranged from 30 to 90 per cent based on a previous five-year average [Padmanabhan *et al.*, 1948]. It was found that while most of the varieties grown were badly infected there was not much loss in the two departmental strains *Kataktara* and *Bhutumuri*. It is not clear how the secondary infection comes about. Unfortunately we have no information whether there was primary infection in the seedlings of the *amam* crop in that year. It is however stated, that the *aus* crop which usually escapes infection was, in this year, badly infected with *H. oryzae*. It is possible that this might have proved the source of infection for the *aman* crop as the period of harvest of the *aus* and a vulnerable stage of *aman* had probably synchronised.

It is believed that peculiar weather conditions, which occur once in a way, are responsible for a severe incidence of the disease. Such weather conditions are continuous rainfall and cloudy weather with a high relative humidity during the months of October-November when ears are forming in the winter crop. A ten-hour period of continuous wetting of the leaves has been found essential for the establishment of the infection [Sherf *et al.*, 1947]. That the source for the primary infection must come through the seed is evident from the fact that the fungus cannot survive in the absence of the host for more than a month under the warm and humid conditions of the rice growing countries [Page, 1947]. In a survey made in Bengal during the years 1943-45 Ganguly [1946] did not come across any alternate hosts carrying the infection of *H. oryzae*. The optimum range for the primary infection from seed is considered to be 18-24°C., but the prevailing temperature in Bengal during July-August is very much higher than this range. This might possibly explain the rather unexpected results which Padmanabhan obtained. He found that an actual sowing of the infected seeds was not followed by the appearance of infection.

The disease due to *Helminthosporium sigmoideum* was first observed in Italy. The fungus causes black, diffuse areas on the leaf sheaths and leaves but the total damage caused is stated to be slight. Outside of Italy, it has been found in Louisiana and Arkansas. Mundkur [1935] obtained the fungus in culture in India and recently it has been reported from Dacca. That this fungus was the conidial stage of *sclerotium oryzae* Catt. was first shown by Tullis and Cralley [1933] who also found that the perfect stage of both these fungi was the ascomycetous fungus, *Leptosphaeria salivinii* Catt. This last named fungus attacks rice leaves causing spots and was also recorded for the first time from Italy.

Stem rot of rice due to *Sclerotium oryzae* (= *Leptosphaeria salvinii* Catt.) probably does not assume serious proportions in India except in the Punjab. The fungus is stated to be very virulent in its attack in Italy and the southern United States. Its sclerotia persist in the soil for a long time and under favourable conditions they germinate and attack the host. Shaw [1913] found that in test tube experiments the fungus was a virulent parasite killing 70 to 80 per cent of the plants within two weeks. Mundkur [*loc. cit.*] made extensive studies of this disease for over three years. Samples of rice plants were collected from eastern, western and southern India and sclerotia of the fungus were detected in a majority of the cases. In experiments on plants grown in test tubes he was able to produce the disease but in field and pot experiments, heavily inoculated with the fungus, both initially and again at intervals, he did not succeed in obtaining the disease. He, therefore, concluded that this fungus under normal conditions did not attack the crop. In the Punjab, however, Luthra and Sattar [1936] have reported that the disease was common in many parts of the province causing a loss of 50 to 80 per cent. They also state that varieties of rice differing markedly in their susceptibility to the disease existed. Presumably the race of the fungus occurring in the Punjab is very virulent and it is also possible that the conditions of environment in the rice growing areas in the province, are more favourable for the fungus to attack the crop in an early stage.

Ikeno [1919] has recorded that susceptibility to stem rot was dominant and was due to a single gene. As the sclerotia overwintered in rice stubble, straw, and the surface layers of the soil, and infected the crop the following year, Tullis, Woods and Carter [1933] recommend the burning of the straw and stubble on the fields. While the sclerotia of the stem rot fungus were not completely killed, it appeared to be a desirable practice. Among other control measures tried was that of withholding standing water from the fields for a period prior to maturity. This appeared to be effective in reducing losses and it is stated that yields might not be lowered appreciably by this treatment as compared with normal irrigation methods. If used in conjunction with the practice of burning rice stubble and straw, it is likely to yield very good results.

(3) *Leaf spot* (*Cercospora oryzae*, Miyake)

Another kind of leaf spot in rice is caused by the fungus named *Cercospora oryzae*; this is common in America. Ganguli [1945] has reported its occurrence in Bengal. Rykar and Chilton [1940] state that three physiological forms of *Cercospora oryzae* could be indentified in America and certain varieties appeared to be resistant to all the strains of the fungus. Adair [*loc. cit.*] has made interesting studies on the inheritance of *Cercospora* and reported that there was difficulty in classifying plants for reaction to the disease in the earlier stages but by carrying on the studies to the fourth generation it was possible to determine the main genes. *Blue rose* a susceptible variety was found to possess a gene dominant for resistance. Apparently several modifying genes were involved for reaction to the fungus and they were not linked with the genes for other characters. He believed that the difference in the reaction to *Cercospora* seemed to be rather due to physiological than morphological or anatomical differences in the rice varieties experimented with, and it was the physiological differences that were inherited. Ryker and Chilton [1942] found that *Blue rose strain* 41 was resistant to race 1 and *Blue rose* was moderately resistant to race 2 but susceptible to race 1. Each of these resistant character was governed by a dominant gene. Close linkage existed between resistance to race 1 and susceptibility to race 2 but in a cross between *Blue rose* and *Blue rose* 41 a few plants were obtained in which the linkage was broken. The gene for *Cercospora* resistance may be designated **Ce**.

(4) *Foot rot* (*Fusarium moniliforme* Sheld)

Another fungus disease which occasionally becomes serious is the foot rot caused by a *Fusarium* which is reported to be common in South India and in portions of Assam. It has been studied extensively by Thomas [1933] in Madras. The outstanding symptom of the disease is the appearance of plants with pale, slender and abnormally elongaged shoots which ordinarily die within a week of the appearance of the diseased condition in the seed bed. When the disease attacks the seedlings, the damage is very serious. Seedlings may start dying from as early as the sixth day after sowing. In transplanted crop the damage is not as bad as in the nurseries. The most characteristic symptom in the transplanted crop was the appearance here and there of tall lanky tillers shooting up conspicuously above the general level of the crop. The abnormal elongation of the infected tillers appeared to be due to an accelerated growth at the expense of lateral development. Plants which show this symptom invariably show fungus attack at the collar region and die within a period of two to six days. Another symptom which is conspicuous on well established plants is the fasciculation of the roots caused by an abnormal branching of the main roots which gives the root system a woolly appearance. A still another symptom associated with the disease is the formation of adventitious roots arising from the upper nodes. No ear heads are formed as a rule and a few that may be formed are chaffy. A similar disease reported from Japan under the name *Bakanae* is now known to be caused by the same fungus.

It has been found that none of the varieties tried at the Paddy Breeding Station, Coimbatore, was absolutely immune but varietal differences ranged from a high degree of resistance (Wateribune, Geb, 24) to almost total susceptibility. In the studies so far made, there appeared to be no association between the disease and other plant characters. Since the studies on the fungus have given evidence that the disease was primarily seed borne, and that seedlings take infection at the time of germination, various seed treatments have been tried to control the disease. Investigations of the Madras Mycologist have shown that the disease can be controlled and remedial measures within the means of the cultivator have been made available. The dressing of the seed before sowing with an organo-mercuric-compound like Ceresan or Granosan effectively controls the disease. A large scale demonstration of such a control costing only four annas per acre has been made in Madras recently.

(5) *False smut* (*Ustilaginoidea virens*)

This disease caused by a fungus called *Ustilaginoidea virens* is found in all the great rice growing areas that bound the Bay of Bengal, Malabar and sporadically in inland tracts like Bihar. The parasite is visible only in the ear stage where it develops in the ovaries transforming them into large velvety green masses. The cultivators on the coast are generally of opinion that a mild occurrence of the disease is an indication of bumper crops which belief seems to be partially true. Estimation of the loss even in very severe cases of attack did not amount to more than one or two per cent of affected ear heads, and even in the affected ear heads only a few grains were damaged the rest remaining normal and healthy. But certain varieties are known to be predisposed to the disease, e.g. Mtu. 10 of the Godavary delta which develops more smut than other varieties. The life history of the parasite has not yet been fully worked out and no remedial measures suggested. It has been found that the crop grown from seed soaked in one per cent formaldehyde for 30 minutes is comparatively more free than the control.

(6) *Striga* (*Striga lutea*)

Though it is not a disease it is known that this flowering parasite attacks rice particularly where rice is cultivated as a dry crop. Uttaman (unpublished records) has studied the *striga* incidence on rice in the *Modan* tracts of Malabar, South India, where definite areas are known to suffer from its incidence making it almost impossible to grow rice there. He found that ¼ per cent copper sulphate solution applied to the infected areas kept the parasite under control but since these dry areas produced a very low acre yield, no economical remedy could be thought of.

14. PESTS OF RICE

Of the losses that occur in the food crops of the world, the toll taken by insects is a large one. Among methods of insect control, modifications in the cultural and agricultural practices sometimes offer a good scope. The position of remedial measures such as spraying or dusting the crop with insecticides has changed in recent years since efficient insecticides are now available for several pests. The biological control which concerns itself with the study and multiplication of particular parasites on the insect pest has proved a fruitful line of investigation in certain cases.

The breeding of pest resistant forms in general is a much more complicated problem than breeding for disease resistance. The reasons are obvious; whereas in many cases of disease one can proceed with a definite knowledge of the life history of the organism, in the case of pests their changing habits together with their numerical strength make the problem more elusive. Whether observed differences in the amount of damage are due to preferences shown by the insect to particular kinds or to the insect's inability to damage certain kinds, it is difficult to determine. Caged material will control population of insects, carefully managed breeding plots and replicated experiments are necessary to study pest resistance. Cases of breeding pest resistant forms are rather rare in the list of achievements of plant breeding. A short account of the work on pests in rice is included for the sake of completeness. For more detailed information, text books on entomology might be referred to.

(1) *The swarming caterpillar,* (*Spodoptera mauritia*)

One of the major pests on rice is the army worm or the swarming caterpillar. The damage is confined to the young stage of the crop and cases of destruction of whole acres of nursery are sometimes reported. Owing to the gregarious nature of the pest, control measures consist only of trapping the caterpillars in their marches at night time by digging trenches filled with water in their path. There is no variety particularly resistant to this pest.

(2) *The paddy stem borer,* (*Schoenobium incertellus*)

This is another major pest on rice all over rice regions and in certain areas and seasons, the damage assumes serious proportions. In Travancore, it is reported there is an annual loss of at least ten per cent of the crop due to this pest. The caterpillar which can be reared only on the rice plant, bores into the stem and kills the shoots and causes the characteristic white ears. A study of the life history of the pest in South India has shown that the pest largely appears from the end of October to early February and by suitable adjustments in the planning and harvest time it is possible to minimise its incidence.

There are varietal differences in the incidence of the pest and these might be due to the differences in the mechanical structure of their stem offering smaller or greater resistance to the boring of the caterpillar. In Madras, strain Geb. 24, is known to be comparatively more resistant to stem borer than other varieties. Generally the fine rice types are more damaged than coarse rices. Variety *Basumati* has been found to be one of the most susceptible varieties. Control measures which consist in the use of light traps to which the adult moths are attracted is successful partly by preventing further spread of the insect. Hand-picking of the egg masses in the rice nurseries also prevents the multiplication of the pest in the later stages of the crop. In other countries where the stem borer is the major pest, flooding the fields and allowing the water to stand and rise in temperature up to 25° to 30°C. is stated to have proved satisfactory in killing the larvae.

(3) *The rice Hispa,* (*Hispa armigera*)

A small bluish spiny beetle attacks the crop both in the larval and adult stages, particularly soon after sowing or transplanting. The damage is caused by the insect eating the green matter of the foliage. Lefroy [1906] records that softer leaved varieties are less attacked than hard leaved ones when there is a choice. Damage due to the pest becomes considerable in a week and less vigorous crop but otherwise no great loss occurs. In Assam and parts of Madras and Orissa, this pest always occurs and assumes serious proportions in some years. Recent work has shown that spraying the crop with DDT 550 or dusting with Gammexane is very effective in controlling the damage.

(4) *The rice bug, (Leptocorisa varicornis)*

This pest is present in almost every rice tract and is characterised by its bad odour. The adult sucks away the juice from the tender ears with the result that the grains remain discoloured and half filled. It is more common in the early varieties of every tract. The pest is a serious menace to the cultivation of early varieties in the United Provinces. The damage done is in some years so great that the cultivators lose more than 50 per cent of the crop. In Assam also it is reported that the *aus* varieties are badly damaged. It is said that in America the pest appears in late maturing rices.

To avoid the pest, the cultivators in the United Provinces generally grow a special short duration variety, *sathi,* in which the ears remain enclosed in leaf sheath. This protective device helps the crop to escape the damage. But *sathi* is a coarse, red-kernelled variety with very poor yields of both grain and straw. The Rice Specialist of the United Provinces has been attacking this problem by breeding new varieties by hybridisation and the attempt may be said to have proved partly successful [Sethi, 1936].

It has not been well established whether the *sathi* variety escapes the pest because it is extremely early and the population of the insect is very low at the time or whether the enclosing sheath does give protection to the ears. Crosses were made between the *sathi* parent and a number of superior strains with the object of transfering the sheathed ear character to other good yielding, better quality rices. It has been found that while various degrees of sheathed ear occurred in the progenies, the full enclosed ear was always associated with the *sathi* type, very early and very poor in yield because of the small ear. Table XIII below summarises the position.

TABLE XIII

Yields of " sathi " hybrids under broadcast conditions

Culture	Duration in days	Grain length / breadth	Average yield for three years expressed as percentages of *sathi* parent
T 12 (Parent)	100	4·38	125
Sathi hybrid 125	96	2·89	121
Do. 130	100	2·58	118
Do. 178	100	2·54	173
Do. 111	100	3·08	108
Do. 118	92	3·90	97
Do. 241	92	3·07	92
T. 131 (*Sathi*) Parent)	74	2·42	100

Remedial measures consist in catching the adult insects by nets which is effective only when the pest is in small numbers. The cleaning of all weeds and grasses on the bunds where it is found to breed in the off-season mitigates the harm later on. Lefroy [*loc. cit.*] states that in Bengal the six-spotted tiger beetles (*Cincindela sixpunctata*) feed upon the rice bugs and keep them in check.

(5) *The rice gall fly,* (*Pachydiplosis oryzae*)

This pest occurs in several places and becomes serious under certain conditions, such as late planting and continuous wet weather. The pest is kept effectively under check by several parasites which simultaneously appear at the time of the outbreak of the pest.

The main symptom of the disease is the production of a hollow tube-like outgrowth from the centre of the shoot in place of the normal shoot with leaves. When the attack is light the plant does not suffer too much as it can produce sufficient tillers particularly with a small application of ammonium sulphate.

There does appear to be varietal differences with regard to the susceptibility to the pest. It is reasonable to assume that in such varieties which have a quick growing period and produce tillers in quick succession, the insect attack does not cause much harm. Geb. 24, a strain of Coimbatore, belongs to this category and it does not suffer from this pest quite as much as other varieties. A variety in Vizagapatam District, Madras, called *Delhi prayagalu* is popularly believed to be more resistant to the attack of gall-fly but no definite studies have been made to confirm this view.

(6) *The paddy mealy bug,* (*Ripersia oryzae*)

Colonies of this minute insect infest the inside of the leaf-sheath and suck up the plant sap with the result that the affected plants, remain stunted, generally turn rusty red and do not produce ear-heads. The affected plants always appear in patches in the fields. The infection is known to start in the nursery and it manifests itself at a later stage in the transplanted crop. The life history of the pest does not seem to have been studied completely and no effective remedial measures are known against this pest. The strain Geb. 24 in Madras which is resistant to many a pest is much more affected by this pest than other varieties.

(7) *The rice thrips,* (*Thrips oryzae*)

Another insect pest which causes damage in the seed beds in seasons of deficient rainfall is the thrip. They suck the juice from the tender leaf blades which get rolled up and the seed bed presents a withered appearance. In a severe attack, the seed beds become very thin and do not give enough seedlings to plant the whole of the intended areas. There appears to exist a certain amount of difference among rice varieties in their susceptibility to this pest [Ramiah, 1937, b].

The pest is controlled by flooding the seed beds with a thin film of kerosine emulsion at the top or spraying with a dilute infusion of tobacco This followed by an application of ammonium sulphate as a top dressing to the nurseries helps the young seedlings to get over the trouble by rapid growth.

(8) *The rice grass-hopper,* (*Hieroglyphus banian*)

This medium sized green insect causes serious damage in certain years, both in the young and adult stages. Eggs are laid under the soil of the field bunds which remain dormant till the break of the monsoon in June-July when they hatch out. The young ones feed first on grasses on the bunds and then attack the rice crop eating up leaves and shoots and often cut off ear-heads also at the later stages. Except mechanical methods of catching the insect by nets and clean cultivation, no remedies are useful. Scraping the bunds and ploughing up the field in the early summer months to destroy egg masses have produced good results when done co-operatively on a contiguous area. Dusting with Gammexane has also been found to control the pest effectively.

(9) *Paddy moth,* (*Sitrotroga cerealella*)

This is a pest of the stored grain and not of the plant causing considerable damage in some places. By occasional cleaning and drying the produce and fumigating the receptacles and godowns with insecticides the produce can be kept free of the insect. Workers in Bombay opine that resistance to paddy moth is an inherited character.

(10) *The eel worm,* (*Tylenchus angustatus*)

Nearly three decades ago, a serious pest from Bengal, Assam and portions of Burma was reported which caused heavy damage to the rice crop. The disease was identified to be due to an eel worm, (*Tylenchus angustatus*) which punctures the cells and sucks away the juice from them; because of its enormous numbers, damage is considerable. It was found more common in late varieties, the early varieties usually escaping the pest. No naturally immune varieties were, however, found and from the nature of the life history of the worm, studied by Butler [1913], no effective remedy could be found. Complete removal of the stubble, mechanically or by burning it followed by early, thorough and repeated cultivation were somewhat useful. It may, however, be noted that the trouble has not again been reported and it would appear that the damage to rice by eel worm can become appreciable only under very special favourable conditions.

CHAPTER XV

CORRELATIONS IN RICE

THE study of correlation between morphological and physiological characters is an important branch of applied genetics. Inheritance studies of quantitative characters is not yet sufficiently advanced to make use of the knowledge of correlations in plant breeding programmes. But the knowledge that correlation exists between two characters should stimulate a study of correlation inheritance and it is, therefore, necessary to record all associations that are met with in genetical studies. The purpose of correlation studies in general is to detect casual relationship between the characters in question. The strength of the association between any two characters is usually expressed by the coefficient of correlation, 'r'.

Physiological and genetical correlations.

Correlation may be either physiological or genetical. Those characters which are influenced by environment and which vary together under the influence of different environmental stimuli may be said to be physiologically related. For, the physiological activity in one character may bring about a corresponding increase or decrease in the measure of another character. The second set of correlations which are genetic has no bearing on environment and is dependent upon the chromosome make-up of the organism. These correlations which may be called linkages are due to genes governing the expression of the two characters residing together in the same chromosome. While the real test of inheritance must be based on pedigree breeding, the correlation analysis is the only method of judging the relationship between parent and offspring.

The distinction between the genetic and physiological correlations is only arbitrary and many cases of physiological correlation may well be genetical. More critical research has yet to be made with regard to this aspect of correlations. It is generally a waste of time and labour endeavouring to break association between characters which are physiologically related. Many of the economic characters, in which the plant breeder is interested in and which he seeks to improve, are quantitative in nature and are known to be influenced to a great extent by environment. If the correlation coefficient is determined from replicated experiments and from progeny means, the effects of environment to which individuals are subject to, are minimised to a great deal. When two characters are genetically related, the scope of simultaneous improvement in both the characters is restricted depending upon the strength of the relationship. If two characters say A and B are associated with a coefficient of correlation 'r' and σ_A^2 and σ_B^2 their genetic variances respectively, selection in character A will also change the mean value of B by a quantity equal to

$r\frac{\sigma_B}{\sigma_A}$ times the change in A and reduce the genetic variance about this mean by a quantity $\nu^2 \partial B^2$ [Pnase, 1940]. This study of covariance is however a recent development and most of the early determinations in rice are based on the orthodox correlation tables from non-replicated plots.

It has been found that all correlations are greatest upon poorer soils and that increased fertility tended to decrease variability. Venkataraman and Subramanyam [1938] in their studies on *jowar* (*Andropogon sorghum*) found that part of the correlation was the result of developmental variation associated with environmental causes, such as differential field effect, border influence or manurial response. Narasingarao [1937] found that in rice under unmanured conditions, the nature of correlations between yield and other characters was the same as under manured conditions but the actual values of correlation coefficients were somewhat higher on unmanured soils.

Intervarietal and intravarietal correlations.

The correlation coefficient in a crop plant, as for instance rice, may be determined in two ways : firstly we have the association that exists between and within the several 'biotypes' or strains that constitute a variety which may be called *intravarietal correlation* and secondly the correlation that occurs between several varieties or pure lines of varieties which may be termed *intervarietal correlation.* Though varieties of a crop belong to the same species with definite capacities to respond to a particular environment, it is worth while to make this distinction in correlation as 'between' and 'within' varieties. It has been reported by Mendiola [1926] that what may be true with an intervarietal correlation may not be true with plants or cultures within a variety. Varietal correlation is not a sufficient guide in selection work. Hence a knowledge about the correlation within the variety is essential, for it is the improvement within the variety that the breeder has to effect in many instances. Yield being the most important of all the characters that a plant breeder is concerned with, and one dependent upon a number of attributes, the correlations between yield on one hand and each of the attributes on the other have received the greatest attention.

Intervarietal correlations.

Average total correlations in rice that are found between yield and other attributes among several varieties have been obtained and are given in Table XIV.

TABLE XIV

Total correlations between yield and other attributes in varieties

Attributes	Berhampur (Medium)	Berhampur (Late)	Chinsurah *aman* (Late)	Chinsurah *aus* (Early)	Coimbatore
Number of tillers ..	+0·54	+0·18	+0·60	+0·85	—0·20
Length of panicle ..	+0·32	+0·21	+0·07	—0·21	+0·35
Number of grain per ear ..	+0·18	+0·13	+0·06	+0·24	..
Height	..	..	+0·10	+0·68	+0·43
Duration	..	..	+0·33	+0·02	+0·32

The above figures indicate that (1) The mean yield is moderately correlated with number of tillers per plant, (2) Height shows a fair amount of correlation with yield, (3) The mean length of ear and mean number of grains per ear are feebly correlated with yield, and (4) Duration, as one would expect, shows a moderate amount of association with yield ; but within an agricultural class, i.e. the late and the early groups, the association between duration and yield is not marked. Mahalanobis [1934] studying the mean measurements of a number of characters for 147 rice varieties of Bengal found, that the mean yield was moderately correlated with the number of tillers per plant and with length of leaf but appeared to be independent of other characters such as, grain dimensions, height, duration, etc. Vibar [1920] has reported that amongst varieties in the Philippines, the following correlations existed :

(a) The longer the duration, the more the grain yield.
(b) Tall growing varieties yielded generally better.
(c) Long leaves and long panicles in general were varietal qualities indicating higher yielding power.
(d) Greater straw weight indicated later growth period but not necessarily heavy yield.

Intravarietal correlation.

(a) *Within a particular strain.* Correlation coefficients have been determined by a number of workers between yield and a number of attributes amongst plants of an individual strain. This type of correlation represents the physiological correlation, being the result of simultaneous action of environmental factors upon the characters concerned. The several correlations are summarised in Table XV.

TABLE XV.

Total correlations between yield and other attributes within a pure line.

Attributes	Berhampur	Nagina (early)	Nagina (late)	Chinsurah (late) *aman*	Chinsurah (early) *aus*	Habiganj *boro*	China	Brigg's Station U.S.A.	Karjat. Bombay
Number of tillers	+0·83	+0·64	+0·87	+0·72	+0·76	..	+0·83	+0·67	+0·8
Length of panicle	+0·28	..	..	+0·25	+0·20	+1·0	+0·45	—0·08	..
Averag numbeer of grain per panicle.	+0·41	..	+0·28	+0·28	+0·55	+0·85	..	..	..
Average height	..	—0·16	+0·41	+0·31	+0·41	+0·66	+·32	+0·06	+0·47
Duration	..	..	..	+0·13	—0·24	..	..	..	..

The results show that :

(1) The number of ear bearing tillers very highly correlated with yield.
(2) Number of grain per ear is the next important character related to yield.
(3) Length of panicle is moderately or feebly correlated with yield.
(4) Height of plant also shows some positive correlation with yield.

(b) *Amongst the several strains of a variety.* This type of correlation is the one the breeder is most interested in and represents largely the genetic correlations between the particular characters. Unfortunately there is not much information available on this type of correlation and the only available figures are those obtained by Narasingarao [1937] amongst strains of three different varieties which are summarised in Table XVI.

TABLE XVI.

Total correlations between yield and other attributes amongst strains of a variety

Attributes	*Boroponk* strains	*Bayyahunda* strains	*Ratnachudi* strains
Number of tillers	+0·54	+0·13	+0·23
Length of panicle	+0·32	+0·29	+0·11
Number of grain per ear	+0·18	+0·16	+0·10
Height	+0·24	+0·14	+0·23
Duration	+0·08	+0·12	+0·14

The results show that in contrast to the correlations within a strain, tillering shows a significant correlation only in one variety and the correlations between yield and other attributes do not appear significant.

The correlations between yield and some minor characters such as length, breadth and thickness of grain, flag leaf dimensions, exsertion, etc. between and within varieties were studied in detail by Chakravarty [1940], Table XVII. Though most of these characters showed no significant relationship, the results are interesting in that they show how different characters behave differently amongst different rice varieties. Breadth and thickness of grain show a greater association with yield in *aus* varieties; and these are in the nature of genetic associations; and hence it is possible to get high and low yielding ones with different grain sizes by crossovers. Amongst *aman* varieties flag leaf breadth and grain dimensions showed however a moderate association with yield. Within a pure line either in *aus* or *aman* group these characters show either a feeble association or no association at all.

TABLE XVII.

Total correlation between yield and minor characters at Chinsurah

Characters	*aus* (Early)		*aman* (Late)	
	Between varieties	Within a strain	Between varieties	Within a strain
Flag length	+0·19	+0·16	—0·05	+0·06
Flag breadth	—0·09	+0·06	+0·34	+0·17
Grain breadth	+0·34	—0·15	+0·12	+0·04
Grain thickness	+0·45	+0·15	+0·21	+0·05
Grain length	—0·41	+0·10	+0·21	+0·10
Exsertion	—0·58	—0·07	+0·01	+0·04

Partial correlations

It happens generally that one character, say A, is correlated with two other characters, say B and C, which are themselves correlated with each other and the correlation between B and C will be partly influenced by the effect of A on each of B and C. Methods are available by which the correlation between B and C could be found with the effect of A eliminated. This is called 'partial correlation' analysis. Partial correlations have been calculated by Narasingarao [*loc. cit.*] between yield and each of the three most important attributes of yield and these are reproduced in Table XVIII.

TABLE XVIII

Showing partial correlations with a strain of different varieties at Berhampur

Symbol	Medium duration B. P. 391	Late duration		
		BHD 1608	RCH 1243	Geb. 24
$r_{12\cdot34}$	+0.879	+0·935	+0·969	+0·820
$r_{13\cdot24}$	+0·130	+0·538	+0·182	+0·088
$r_{14\cdot23}$	+0·768	+0·728	+0·574	+0·457
$r_{23\cdot14}$	+0·351	—0·608	—0·157	+0·237
$r_{24\cdot13}$	+0·360	—0·770	—0·546	—0·317
$r_{34\cdot12}$	+0·830	+0·591	+0·532	+0·614

1. Yield.
2. Tillers (bearing earheads) per plant.
3. Average length of panicle, in cm.
4. Average number of grain per panicle.

It is found that in all cases the correlations between yield and number of tillers improved with the elimination of the other two characters. The results between yield and length of ear becomes negligible when the influence of the other two characters is eliminated. Number of grains per ear shows a higher association with yield in partial correlations. The partial correlations between number of grains and tillers and those between tillers and length of head are negative in these cases.

Multiple regression

This procedure of removing the effects of one character in determining the correlation between two others with which this character is related may be extended to a number of characters which results in the determination of multiple regressions and multiple correlation coefficients. The multiple regression equation serves to sum up all the evidence of a large number of observations in a single statement, and it expresses in a condensed form the extent to which differences in the dependent variable tend to be associated with differences in each of the independent variables. A good example of this multiple correlation analysis has been worked out by Venkatraman and

Subramanyam [*loc. cit.*] in *jowar* (*Andropogon sorghum*). Narasingarao [*loc. cit.*] has determined the multiple correlations in strains of 4 different varieties of rice and the results are given in Table XIX.

TABLE XIX

Multiple correlation coefficients

Nature of correlation.	B. P. 391	BHD 1608	RCH 1243	Geb. 24
$R_{1\cdot34}$	0·3610	0·5259	·2757	0·5259
$R_{1\cdot23}$	0·7700	0·8400	0·8930	0·8560
$R_{1\cdot24}$	0·8408	0·9198	0·9069	0·8780
$R_{1\cdot234}$	0·8520	0·9284	0·9295	0·8786

1. Yield gm. per plant.
2. Number of tillers per plant.
3. Length of ear in cm.
4. Number of grain per ear.

Multiple regression equations

B.P. 391 .. .. .. $X_1=1{\cdot}97X_2+0{\cdot}26X_3+0{\cdot}081X_4-14{\cdot}88$

BHD 1608 .. .. .. $X_1=2{\cdot}72X_2+0{\cdot}46X_3+0{\cdot}111X_4-24{\cdot}37$

RCM 1243 . .. .. $X_1=2{\cdot}65X_2+0{\cdot}36X_3+0{\cdot}071X_4-9{\cdot}11$

Geb. 24 .. .. .. $X_1=1{\cdot}63X_2+0{\cdot}241X_3+0{\cdot}113X_4-14{\cdot}88$

The equations are very definite in showing the predominant influence of the number of tillers on plant yield. An increase of one tiller increases the yield per plant by 1.5 to 3 gm. in different varieties. The influence of increase in length of ear on yield is less compared with the influence of number of grains per ear. Considering the values of the individual multiple correlation coefficient, $R_{1\cdot234}$ has the highest value but its differences from $R_{1\cdot23}$ or $\mathbf{R}_{1\cdot24}$ are small which means that we need to consider only either the length of ear or the number of grains per ear. $R_{1\cdot34}$ is only 0.361 showing that only a small part of the variation in yield could be explained by the combined action of length of ear and number of grains per ear.

The real aim of the plant breeder is to approximate excellence in all the essential factors, and there seems to be no information for basing yield excellence on any one feature, such as tiller number, ear length, etc., and the only unit on which we must work, is the living plant itself and not its individual organs. But the latest statistical development of discriminant function which takes into consideration the effect of multiple attributes giving to each attribute its appropriate weight in determining a particular economic character, say, yield, is a helpful guide to the plant breeder. It is hoped breeders will bestow some attention on this particular aspect.

Kondo and Naguchi [1922] in their studies on quantitative characters in selected plants of eight varieties of rice and in the progeny of each plant, found positive correlation to exist between the parent and its progeny with regard to yield, number of kernels on panicle, density, (spacing of kernels on the panicle), 1,000 kernel-weight and culm length. No definite correlation was found regarding number of culms, total plant weight, grain or straw weight.

Other associations

We can now mention some of the associations that have been recorded between characters, qualitative and quantitative. During the course of investigations on the varieties of the deltas of Godavary and Kistna at the Agricultural Research Station, Maruteu, Srinivasan [1926] found that the light green colour in the vegetation was associated with vigor, earliness and greater prolificacy. Bhide and Bhalerao [1926] have found a certain amount of association between hairiness of leaf and coarseness of grain. Ramiah [1927, b] found that narrow width of leaf was associated with finer grain size. Joshi and Gadkari [1923] found a significant correlation between the thickness of the lowermost internode and length of ear, $r = 0.781 \pm 0.012$.

In one variety *Atragada* Srinivasan [*loc. cit.*] noticed that compact tillered, narrow leaved strains had fine grain with white kernel and were longer in duration while those with a spreading habit of tillering and coarse leaves had light red rices. Anandan [1928] found that varieties with purple husk and purple rice were slower in germination than those with straw husk and white rice.

It has been the general experience that rice is sensitive to atmospheric conditions and a number of popular beliefs regarding weather and yield are extant, and they may be verified by examining them by correlation studies. No extensive investigation appears to have been made in this direction, but Khadilkar [1934] found some interesting correlations between some plant characters and weather factors, specially rainfall and maximum temperature during the growing period of the rice crop. The culm height varied directly with the July rainfall. The August rainfall influenced weight and number of fertile grains in main panicle, length of panicle and size of grain. Heavier rainfall in October delayed flowering and increased the weight of straw per plant and *vice versa.*

Other methods of determining associations. The most useful method, namely, the product moment correlation coefficient, **'r'**, has been illustrated in the preceding paragraphs. However, cases occur where the data under consideration do not conform to the basic assumptions for the calculation of the above coefficient such as linearity of regression. Besides, it may not be always possible to measure both the characters admitting only categorical classification. Statistical methods suitable to deal with such data are available. The first case where the regression is non-linear could be treated by the correlation ratio, while the second type of data could be treated by means of contingency tables and χ^2 tests. In the special case where one character is a dichtomy while the other is quantitative, the biserial correlation coefficient η could be used. Ramiah [1933, a] has recorded an association between lemma colour and duration (Table XX).

TABLE XX

Association between lemma colour and duration

Colour of lemma	Flowering durations in days						Total
	92 and below	93 to 98	99 to 104	105 to 110	111 to 116	117 and above	
Brown ..	187	317	280	129	61	12	986
Gold ..	16	49	59	92	78	31	325
Total ..	203	366	339	221	139	43	1311

The biserial η for the above data is $+\ 0.5497 \pm 0.0294$ which shows a fairly high correlation between duration and glume colour.

Thus the study of correlation is useful to the plant breeder in that he will be able to distinguish the genetic from the physiological correlations and give due weights to them. A knowledge of the genetic association between an economic character and certain of its visible attributes helps to base selection for the invisible character on its visible attributes.

CHAPTER XVI

LINKAGE IN RICE

According to the chromosome theory of heredity, the genes governing the expression of every character of an organism are not only located in the chromosome, but are also arranged in a linear order along the length of the chromosome. The genes located in the same chromosome tend to be inherited together as a whole and are said to be linked and the phenomenon is termed linkage. This linkage is, however, never absolute as sometimes the linked genes occur separated from each other. Those cases in which linked genes break apart from their original combinations, or in which genes originally separate become united in one gamete or individual, are known as cross-overs and recombinations respectively. For details of linkage and crossing over, how and when they occur, etc. any text book on cytogenetics might be referred to.

It has been found that the number of linkage groups corresponds to the haploid number of chromosomes in the species. This result first determined in *Drosophila* has been found to be applicable to the cases of other plants and animals. Such studies have led to the construction of the chromosome maps specifying the actual locus of each of the genes in the chromosome, the data on linkage and crossing over providing the information on the chromosomal distance between individual genes. In modern genetical studies the determination of linkage groups in the organism has proved a valuable tool in the analysis of the complexities of heritable differences. In plant breeding, a knowledge of the strength of linkage among genes controlling particular characters is therefore valuable.

Rice has twelve pairs of chromosomes and we should, therefore, expect all its known genes to fall into twelve linkage groups. Though considerable progress has been made in the genic analysis of several characters of the plant, the identification of the actual groups is still only in the initial stages. Satisfactory techniques of identifying groups are now available but cytogenetical knowledge of rice has not advanced far enough to make use of these methods. The only method that has been followed so far is the tetrad analysis, and even the method of back-crossing the hybrid to the parents has not been made use of extensively, owing to the comparatively greater difficulty in producing a large number of hybrid seeds.

Matsura [1933] has summarised all the published results on linkage studies up to 1929 and these are mentioned below*:

1. A gene **Ap** for reddish colour in lemma apiculus is linked with a gene **wx** for starchy endosperm with 20—22 per cent of crossing over, [Yamaguti, 1921, 1926 (b), 1927 (a), 1929 (a) and 1929 (b); Takahashi, 1923; Chao, 1928 (a)]. It was later identified that one of the genes for heading time **Fl** was another member of this group. The following values of crossing over have been obtained in different cases: between **Fl** and **Wx** 8.8 to 24 per cent and between **Fl** and **Ap** 20 to 24 per cent. The order of these genes was supposed to be **Ap—Wx—Fl.** Chao [*loc. cit.*] added still

---

* The genic nomenclature used here are those suggested by Kadam and Ramiah [1943].

another gene to this group, **G-t**, a gene for tawny ripening colour of the awn, glume, lemma and apiculus. The percentage of crossing over between **G-t** and **Wx** was found to be 16.6 per cent. He states further that the genes **Ap**, **Spa** (one of the complementary genes for stigma colour) and **Lsp**$_1$ (one of the complementary genes for leaf sheath colour) are either closely linked or identical with each other. Yamaguti suggests the presence also of a semi-lethal gene in this group to account for the deviations from the normal ratio in the segregation for the gene **Wx-wx**.

2. A gene for red pericarp colour **Pr**$_1$ was found by Yamaguti [1929, a] and [1929, b] to be linked with one of the genes for heading time, **Fl** with a crossing over percentage of about 22. **Pr**$_1$ proved to be independent of both **Ap** and **Wx**.

3. A gene for the ripening black colour of the lemma, **H-b**$_a$ or **H-b**$_b$ (wrongly quoted as dark gold by Matsura) was found by Parnell *et al.* [1917] to be linked with a gene **Ntv** for purple lining of the internode with a crossing over of 16.8 per cent.

4. A gene for coloured ligule **Lgp** is linked with a gene for coloured lemma **Hp** with 12.5 per cent of crossing over [Hector, 1922].

5. There is almost complete linkage between two genes for sterility **fst** for staminoidal sterility and **fp** paleaceous sterility, [Nagai, 1926].

6. A gene for spikelet length **K**$_1$ is linked with one of the duplicate genes for glume length **g**$_2$ with a crossing over of 1.1 per cent [Chao, *loc. cit.*].

7. One of the complementary genes for stigma colour **Sp**$_2$ is linked with one of the complementary genes for leaf sheath colour **Lsp**$_3$ with a crossing over of 9.8 per cent [Chao, *loc. cit.*].

8. A gene for purple caryopsis (lemma), **Hp**, is very closely linked or identical with one of the complementary genes for ligule colour, **Lgp**.

According to Chao [*loc. cit.*] *items* 1, 6, 7 and 8 above constitute four linkage groups; their relation to others has not been established with certainty yet. Groups other than 3 and 4 refer to results obtained outside India. Linkage results that have been recorded since 1928 might now be referred to.

Chao [1934] who has made further contributions to linkage studies mentions a gene controlling ripening character of awn (green changing to yellowish brown), linked with glutinous endosperm gene **Wx** with a cross-over value of 20 per cent. It is not known whether this character is different from the tawny which he had reported in his earlier publication and for which he had given a cross-over value of 16.6 per cent. He has confirmed that the genes g$_1$, g$_2$ responsible for size of glume are independent of the glutinous and grain husk genes. His study of the long and short spikelet has shown that the gene for short spikelet **K**$_1$ was closely linked with the gene for glutinous endosperm, **wx** which is linked at least with four other genes including that for leaf sheath colour. He also states that the colour of the ligule is independent of the glutinous character, **wx** but closely linked with lemma colour, **Hp**.

Yamaguti [1932] studied the linkage relations of several genes, **Lp**$_1$, **Lp**$_2$ controlling colour in the leaf blade, **wx,** glutinous gene, **Lp**$_3$ another gene for leaf colour, **D,** gene controlling growth habit and **Fl**$_2$,· **Fl**$_3$ controlling heading time, in a cross by testing them in pairs in various combinations. He found linkages between **Lp**$_1$**—Wx, Lp**$_3$**—Fl**$_3$ with a cross-over of 30.7 per cent, **Lp**$_2$**—Fp**$_3$ with a cross-over of probably 33 per cent, and **Wx—Fl**$_3$ with a cross-over of 40 per cent in one case but no linkage in another. He also found that the relation between **Lp**$_1$**—Lp**$_2$ and **Lp**$_1$**—Lp**$_3$ supported his assumption that the genes **Lp**$_1$ and **Lp**$_2$ were identical.

Takahashi [1935] further investigated the linkage between endosperm gene, **Wx—wx** and lemma apiculus colour gene **Ap** which is also responsible for colour in the awn, **Ap Anr** (red), **ap Anr** (yellowish white) and **Ap anr** (yellowish white changing later to red). While there was linkage between **Wx** and **Ap** with a cross-over of 21 per cent, there was no linkage between **Wx** and **Anr.** He also found [1939] that **Wx** was linked with a gene **Fs** affecting spikelet fertility with a cross-over of 2.2 per cent.

Morinaga [1938] has recorded linkage between gene **Lp**$_1$ for full purple colour in the leaf lemina and gene 1*g* for liguleless with 21-22 per cent cross-over.

Jodan [1940] has determined the linkage relationship among five genes controlling endosperm character **wx,** lemma apiculus colour **Ap,** cluster arrangement of the spikelet, *cl,* virescent, **v** and heading time **Fl** and shown that all of them are located in the same chromosome (Group 1 mentioned earlier) thus adding two more genes **v** and **c** to the group determined by Yamaguti and Chao. While he could determine the locus of all the 4 genes he could not be certain of the locus for the gene **Fl** controlling heading time.

While all the results referred to above deal mainly with morphological characters, a case of linkage in physiological characters has been recorded by Ryker and Chilton [1942] who state that the resistance of Blue Rose 41 to race 1 of *Cercospora oryzae* is conditioned by a single dominant gene **Ce**$_1$ and the moderate resistance of Blue Rose to race 2 by another dominant gene **Ce**$_2$. Close linkage exists between resistance to one race of the fungus and susceptibility to the other. In crosses between Blue Rose and Blue Rose 41 some plants are obtained in which this linkage appears to be broken.

The results of linkage studies obtained in India, can now be referred to :

1. The first case of linkage recorded was between the gene **H-b**$_a$ or **H-b**$_b$ and **Nty** and this has been referred to already.

2a. Ramiah *et al.* [1931] has recorded as case of linkage between the gene for the glutinous endosperm. **Wx** and one of the complementary genes for producing anthocyanin pigment in lemma, apiculus ; **Ap,** with 29 per cent cross-over.

2b. Parthasarathy (unpublished records) has shown linkage between pigment in lemma apiculus and clustering of the spikelets, thus confirming the linkage recorded by Jodan.

Obviously 2a and 2b belong to group 1 of Yamaguti, Chao and Jodan though the percentage of cross-over between **Ap** and **Wx** is different in the two cases.

3. Ramiah [1937, a] has recorded linkage between pericarp colour gene **Prp—prp** and one of the complementary genes for scent or aroma in the grain **Oa** or **Ob** with 14,7 per cent cross-over.

4. Anandan [1933] has recorded linkage between the gene **Kr** for small round shape of grain, a simple dominant over long oval grain, and awning genes $\mathbf{An_1}$, $\mathbf{An_2}$. He obtained 15 : 1 ratios of awned to awnless in one case and 3 : 1 of awned to awnless in another with 13.6 and 24.1 per cent cross-over respectively.

5. There was observed another case of linkage (unpublished records of Coimbatore) between the depth of purple colouring in the internode and rice pericarp colour **Pr.** A variety with ordinary puple lined internode and red rice was crossed with another having very dark bluish lines in the internode and white rice. The F_1 had dark internode very much lighter in colour than in the second parent and in the F_3 there was a clear segregation for the depth of colour in the internode as well as for rice pericarp colour as shown below :

	Light purple internode	Dark lined internode	Total	Percentage of cross-over
Redpericarp colour	**Pr. 1703**	**242**	**1945**	
White pericarp colour	**pr. 260**	**433**	**693**	
	1963	**675**	**2638**	**20·9**

6. Ramiah (unpublished records of Coimbatore) has obtained results showing linkage between purple apiculus, **Ap,** lemma colour (green stage) **H***pb*-**H***f* and lemma colour ripe stage (husk colour) **H-b.**

	Purple apiculus **Ap.**	Green apiculus **ap.**	Total	Percentage of cross over.
Dirty *H pb*	280	48	328	
Brown furrow *H f*	68	63	131	
	348	111	459	28·7
	Lemma colour young stage			
	O. dy. *H pb*	Dy. brown furrows *Hf*	Total	
Ripening black	**234**	**122**	**366**	
Ripening straw	**94**	**9**	**103**	27·3
	328	**131**	**469**	

Since there are more than one gene concerned with purple apiculus, it cannot be said whether this gene is the same as that dealt with by Chao and Iodan. In the material dealt with by Parnell mentioned in 1 supra showing linkage between **Ntv** and **H-b**$_a$ or **H-b**$_b$ all the plants had purple apiculus but was segregating for colour of the internodes only. The gene for apiculus colour referred to in 6 is the same as mentioned in 2 showing linkage between apiculus and endosperm character. The actual identity of the gene concerned in ripening character of lemma can be made out only by further test crosses.

7. A large number of crosses specially made between known parents as well as natural crosses occurring in pure lines have been extensively studied at Coimbatore, and Ramiah [1935] has indicated that the several genes controlling the development of anthocyanin pigment in different organs of the plant fall into 3 or possibly 4 linkage groups. Two of the groups he obtained from the study of the crosses T.102 × T.29 and T.102 × T.6 were :

Group I. Pigment present in

Lsv	Leaf sheath, lines.
Ntp	Internode.
Lax	Leaf axil.
Jp$_1$	One of the duplicate genes for junctura.
Aup$_1$	One of the duplicate genes for auricle.
Lgp$_1$	One of the duplicate genes for ligule.
Sp	One gene for stigma.
Hp$_1$	One gene for lemma.
Ap$_1$	One gene for apiculus.

Group II. Pigment present in

Lsp	Leaf sheath (without lines).
Jp$_2$	One of the duplicate genes for junctura.
Aup$_2$	One of the duplicate genes fo auricle.
Lgp$_2$	One of the duplicate genes for ligule.

Later studies (unpublished records) have shown that a gene for purple septum and a gene for purple ripening colour of lemma also belonged to Group I of above.

Since the above studies in a large number of crosses involved the glutinous endosperm also, **wx**, and there was observed no linkage between **Wx** and the pigment groups I and II, this gene obviously belongs to a third pigment group which may be the same studied by Yamaguti, Chao and Jodan. The members of this group from Coimbatore studies will be :

Group III

Ap$_2$	A gene for purple apiculus.
wx	Gene for glutinous endosperm.
cl	Gene for clustered spikelet.
H^f	Gene for dirty brown furrows in lemma.
H-b$_a$ or **H-b**$_b$	One of the genes for ripening black colour of lemma.

It is possible that the gene for purple lined internode **Ntv** showing linkage with one of the ripening black genes of lemma belongs to this group or it belongs to a still another group. While discussing lemma colours in Chapter XIII of Part III, it was shown that there were four genes definitely forming a multiple allelomorphic series, $\mathbf{H}^{m}$, $\mathbf{H}^{pb}$, $\mathbf{H}^{g}$, and $\mathbf{H}^{f}$. Since one of these $\mathbf{H}^{f}$ has been found to belong to group III, it follows that the other three should also belong to this group.

In the crosses referred to which gave the clue to the existence of two distinct anthocyanin groups, it was found that a large number of genes go together. While discussing anthocyanin genetics in Chapter XII, it was shown that varieties where pigment is present in various organs appear in so many combinations or patterns, each breeding true as if a single gene was involved. It has been assumed that the genes responsible for producing pigment in different parts of the plant are different but remain linked. There is, however, the alternative possibility that a single gene in particular combination might produce colour in more than one part. This possibility should involve the postulation of a multiple allelomorphic series. The aberrant types different from the parental combinations often occurring in cross progenies should be considered as cross-overs under the linkage hypothesis or mutations under the multiple allelomorph hypothesis.

The two crosses T.102 × T.29 and T.102 × T.6 do provide some information on the two hypotheses. The crosses which were studied very extensively in F_2, F_3 and F_4 generations showing very strong linkage of the parental characters gave a small number of aberrant types showing breakage of linkage as shown below :

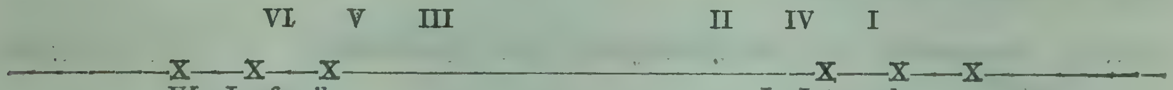
	T. 102	T. 29	T. 6
Leaf sheath	Green	Purple self colour as well as lines.	Green sheath with purple lines only.
Internode	Dark purple, almost black.	Purple lines only	Purple lines only.
Lemma	Dark purple	Green	Green
Lemma apiculus	Do.	Dark purple	Dark purple
Leaf junctura	Do.	Green	Green
Auricle	Dark purple	Green	Green
Ligule	Do.	Light purple	Do.
Septum	Do.	Pink	Pink
Leaf axil	No colour at the actual base.	Dark purple	Dark purple
Stigma	Light purple only a few feathers coloured.	Do.	Do.
Rice pericarp.	Purple	Red	White

In both the crosses the F_2s consisted only of the two parental groups in the proportion of 3 : 1 with regard to all the characters except in the case of leaf sheath, auricle and ligule in the cross T.102 × T.29 and auricle only in the cross T.102 × T.6 which gave a duplicate factor segregation. While the details of the results of these crosses will be discussed in a separate publication, it will be enough to mention here only three of the characters of the aberrant plants.

Aberrant types

	(a)	(b)	(c)$_1$	(c)$_2$
Internode	Dark purple	Ordinary purple lines.	Dark purple	Dark purple
Lemma	Green	Dark purple	Do.	Do.
Rice pericarp	Purple	Red	Red	White
Number of plants	4	6	1	1
Percentage of the aberrants to the total F_2, F_3 and F_4 population.	0·025	0·037	0·006	0·006

While the aberrant types (a) and (b) might be considered cross-overs by breakage of linkage between points II and III in the diagramatic representation shown below, type c would have to be considered as resulting from breakage between points I and II as well as between II and III.



VI—Leaf axil.
V—Stigma.
III—Lemma.

I—Internode.
IV—Junctura, auricle and ligule.
II.—Rice pericarp.

Types (a) and (b) are complementary and though the complementary cross-over type for (c) did not occur in these crosses, it did in an analogous cross studied later. That the double cross-over type (c) occurred in even smaller proportions than (a) and (b) does satisfy the requirement of linkage and crossing over hypothesis. Beyond determining the breeding behaviour of the above aberrant types, no genotypical tests were made with them. In an analogous cross studied some years later at Coimbatore, aberrant types corresponding to types (a) and (b) occurred once again in extremely small proportions, and they were later crossed with either of the parental types and with each other. It was found that the new recombined set of characters, namely, dark purple internode and green lemma and ordinary purple lined internode and purple lemma were inherited as separate units showing that they could have arisen by mutation. The extremely small proportions in which the recombination types occur would rather seem to support the mutation theory. Further investigations would appear necessary to decide the issue, linkage and crossing over versus multiple allelomorphism-cum-mutation. While in the particular crosses studied there was found no instance in which the linkage between leaf axil and stigma got broken, there were other crosses in which it did.

The linkages or genetic associations so far described refer to simple morphological characters, more particularly those relating to the presence or absence of anthocyanin pigment in different parts of the rice plant. Where quantitative or physiological characters are concerned, they are often controlled by multiple genes and the determination of the degree of linkage becomes difficult except where such characters are controlled by one or two genes only. Where a morphological and a quantitative character are concerned, the association or relationship between the two is best expressed by a two-way table, and where both the characters concerned are quantitative in nature, the correlation coefficient is about the best means of expressing the associationship between the two. In the inheritance studies followed at Coimbatore, several cases of genetic association between morphological and quantitative characters and between different quantitative characters have been recorded, and they may be dealt with briefly. Before doing this we might consider another category of association between morphological characters which can be simple physiological or anatomical associations and not genetical. Associations of this category are : narrow leaf blade and narrow or fine spikelet [Ramiah 1927, b]; panicle density and size of grain, smaller length of the panicle and clustering of spikelets, panicle density and grain size with spikelet sterility [Ramiah, 1931]; virescent and reduction in vigour, [Ramiah, 1930]; larger grain and multiple pistil [Parthasarathy, 1935]; light green foliage, earliness and greater prolificity [Sreenivasan, 1929]; hairiness of the leaf and coarseness of the grain [Bhalerao, 1926]; thickness of the lowermost internode and length of panicle [Joshi and Gadkari, 1923]; slower germination of grain with purple husk [Anandan, 1928]; poorer tillering and non-lodging nature of straw [Ramiah and Mudaliar, 1934]; shattering and round shape of grain [Ramiah and Hanumantha Rao, 1936]; etc.

Genetic association of morphological and quantitative or physiological characters

1. The first recorded instance of such an association was by Parnell *et al.* [1922] where the dark, medium and ripening gold colour of the lemma were associated with definite grain size and shape. It is possible that a gene for grain shape is closely linked with the lemma colour gene or the lemma colour gene itself determines the grain shape.

2. In a cross studied by Ramiah [1931] the F_2 was segregating for the presence and absence of anthocyanin pigment in leaf axil and stigma and also for spikelet sterility. A joint tabulation of the two segregations gave a mean fertility percentage of 53.7 ± .043 for the pigmented group and a mean percentage of 78.2 ± .034 for the non-pigmented group showing genetic association between the pigment gene and the sterility genes. In another cross where there was segregation for anthocyanin colour on lemma he found that plants with purple lemma were more fertile than those with green lemma, the difference being highly significant in terms of the error.

3. Ramiah [1933, c] has recorded a case of genetic association between colour of lemma and flowering duration. The segregation in lemma colour was for the gene Ih giving 3 brown to 1 gold, and it was found that the mean flowering duration of plants with gold lemma was always significantly higher than for the brown lemma in all the F_3s examined. Since the segregation for flowering duration was of the multigenic type, the degree of linkage

could not be determined. This cross was segregating for plant height also and all the plants with gold lemma were taller than those with the brown lemma, thus showing linkage among genes **Ih, Fl** and **T.**

The gene for red pericarp colour **Pr** must also belong to the above group, as **Pr** in the presence of **Ih** makes the pericarp colour gold. Hector [1922] records that in *aus* varieties of Bengal there is a strong association between anthocyanin colour and earliness and that absence of pigment is associated with lateness in *aman* varieties.

4. In two sets of crosses studied by Ramiah and Mudaliar [1934] where the non-lodging nature of the straw proved a simple recessive to lodging nature, *Ld-ld*, it was found that the non-lodging plants had fewer tillers, were later in flowering duration and had greater spikelet sterility than the lodging plants. There was, however, no association between lodging nature and plant height.

5. The inheritance of floating habit has been studied by Ramiah and Ramasamy [1941, a] and they found that the floating habit was controlled by duplicate recessive genes **ef**$_1$, **ef**$_2$. The floating habit was found partially associated with a compact type of tillering. The family was also segregating for plant height and flowering duration, and there was definite linkage between flowering duration and floating habit with a 30 per cent cross-over.

6. Parthasarathy [*loc. cit.*] has recorded that multiple pistil is a sinmple recessive to single pistil and that in an F_2 involving segregation for this character and spikelet sterility (multigenic) there was linkage between the two characters, multipistillate plants having a significantly higher mean spikelet sterility than the normal plants.

Genetic association between quantitative characters

1. *Panicle exsertion.* The degree of panicle exsertion is a quantitative character controlled by multiple genes and in an F_2 of a cross segregating for this character Ramiah [1931] found that there was a very high positive correlation between poor exsertion and greater spikelet sterility, the coefficient of correlation being + 0.92 ± .02. He also found a high negative correlation between ear exsertion and flowering duration (correlation coefficient being —0.96 ± .05) in the same cross. The correlation between duration and sterility was also high. Thus a linkage is established among spikelet sterility **fs,** flowering duration **Fl** and ear exsertion **Fx.** Similar association has also been recorded by Jones [1930, b]. Ear exsertion has also been found to be positively correlated, though not so highly with height of plant and length of ear [Ramiah, 1933, c] in another cross.

2. *Plant height and flowering duration.* Ramiah [1933, a and b] has shown that the two contrasting pairs of characters short-tall and early-late may be controlled by a single gene, two genes and more than two genes. In the several crosses he had studied, he found that while there was no association between plant height and flowering duration in some, they were closely associated in others. In the crosses T.102 × T.29 and T.102 × T.6 already referred to, short plants were always early and tall plants were always late, the mean correlation coefficient being of the order of + 0.75 ± .02. Even in a cross where the two characters were controlled by multiple genes, he found a high positive correlation between the characters.

The absence of any correlation between the two characters in some crosses and the presence of a high correlation in others led him to assume that the genes controlling these characters were linked. Ramiah also found that these two characters showed genetic association with other quantitative characters like ear length and ear exsertion.

In the crosses he examined, Ramiah also found that wherever there was segregation for short-early and tall-late, the mean yield per plant of the latter group was always very much higher than the mean of the former group. This increase he found was rather proportional to the difference in the duration between the two groups, the larger this difference, the greater the yield increase.

Grain size. In the Chapter dealing with the genetics of grain size, it was shown that both grain length and grain width were controlled by multiple genes, but the studies of Ramiah and Parthasarathy [1933] showed a definite positive correlation between length and length/breadth ratio (correlation coefficient + 0.60 ± 0.18) indicating that long grains tended to be narrow. This correlation was definite and high in all the crosses they studied.

It would be clear from what has been discussed so far that we have touched only the fringe of this important subject, namely, the determination of linkage groups. Nearly 300 genes have so far been discovered concerning about 50 major characters of the plant, and with the information available so far, we can recognise about four linkage groups only involving about 30 genes. There are certain genes which so far have not shown any linkage relationship with other known genes indicating that they may be present in the other eight chromosomes. It should be possible by undertaking extensive experiments to assign all the known genes controlling morphological, quantitative and physiological characters to particular linkage groups. The chief requirement for this study is to make a collection of all the genic types at one centre and plan out a comprehensive programme of hybridisation. A useful collection for such a work has been made at Central Rice Research Institute, Cuttack, and if necessary, further material not available there, can be collected from other centres either in India or abroad. What is needed is for a competent rice geneticist to start the work on a well designed plan. It should be preferable to start the investigation at one centre and extend it to other centres later on a coordinated plan. The great progress that has been made with maize genetics in the U.S.A. is due to the coordinated plan of work carried out by all the maize geneticists working in the different Universities and Agricultural Colleges of the States.

CHAPTER XVII

MUTATIONS IN RICE

MUTATIONS may be defined as 'sudden changes in heritable units, transmitted in a more or less constant new form to subsequent cell generations.' Recent developments have provided valuable tools to the biologists to produce mutations artificially, the most important of such tools being the X-rays and the chemical, colchicine. Certain other agencies like ultra-violet light, exposure during anthesis to high intensity illuminations, centrifuging, soaking seeds or seedlings in various chemical solutions, sudden changes of temperature, growing very aged seeds, etc. may also help in producing mutations similar to those resulting from X-ray treatment. According to the unit of change, mutations can be classified into three groups : (1) gene mutations, (2) chromosome mutations, and (3) genome mutations. It is not often possible to distinguish from the external behaviour, effect due to single genes from those involving groups of genes and whole or portions of chromosomes.

X-ray mutations

As mentioned already, X-ray is the most potent force in speeding up mutations and all the artificial mutations in rice described here are those obtained from X-ray treatment. As regards the mode of action by X-rays, it has been suggested that the changes induced are due to the direct bombardment of the nucleus by the energised electrons. This may alter the gene or break the chromosome at any locus. Muller [1930] observed that mutations occurred in either directions in *Drosophila* and hence it was irreconcilable with the common view that all mutational changes by X-rays consisted only of losses. He was of the opinion that progressive mutations can also be induced by X-rays in cases where there was a possibility of their occurring at all. Several lethal characters have been reversed to the normal condition by X-raying in the naploid sperm in *Drosophila*. The successful application of X-ray to economic plant breeding is still a matter of dispute. The scope of X-ray effect may be unlimited but the results cannot be controlled as the changes occur absolutely at random. In the hands of the breeder it is a quick but speculative method not only of inducing new variations but also of breaking up certain undesirable combination of characters due to linkage. Though most of the induced mutations are recessive and useless from the view point of practical breeding, they offer a wide range of material for genetical studies. Production of even haploid and polyploid forms has been claimed by the use of X-rays. Tanaka [1941] obtained a successful interspecific hybrid by X-raying the pistils of spelt wheat for 30 minutes and later pollinating them with pollen from plants of *Timopheevi* species. Horlacher and Killougn [1932] have recorded strong evidence for the occurrence of dominant progressive mutations as a result of irradiation in cotton. Ramiah (unpublished records) obtained in Malwa Upland Cotton a mutation with higher ginning percentage and fibre length by X-raying one of the established strains.

Mutations affecting every part of the rice plant as well as many of its physiological characters, for example, sterility, have been reported. Sakai [1938] exposed seeds and young seedlings of rice for a certain duration of time to the X-rays delivered without filter from a Coolidge tube with copper anticathode. The quantity of the rays used by the author was expressed by the formula $\text{MA-M}/D^2$ at 30 K.V., where MA was the intensity of the secondary current potential, M, the duration of radiation expressed in minutes, D the distance of the material to be radiated (always 21 cm. in author's experiments) and K.V., the secondary current potential. The samples were exposed to various MA-M lying between 0 and 10,000. It was found that the germination of seed was quicker and there was increase in the number of tillers, ears and grains and also in the weight of straw, roots and grains when the exposure did not exceed 50 MA-M. In short, the effect of X-rays was favourable, when it did not exceed 50 MA-M; where it did, there was a general inhibitory effect. Ramiah and Parthasarathy [1938] were the first in India to use X-rays for producing mutations in rice. Their work at Coimbatore, has produced a large number of mutations affecting various characters like size and habit of the plant, size and arrangement of grain in the panicle, fertility of the spikelets, chlorophyll deficiencies, etc. Thirtysix mutations affecting different characters and sixteen chlorophyll deficient types have been studied adding to our knowledge about rice genetics. It may be mentioned that one of these mutations has proved useful from the economic point of view. It has a slightly shorter stature with a larger number of tillers than the original parent material, and has proved valuable in that it does well in rich soils where the problem of lodging is serious [Sreenivasan, 1941]. Their treatment consisted of exposing dry seed, unscreened under a water cooled Coolidge tube with copper anticathode operated at 53 K.V., and a tube current of 10-11 MA at a target distance of 17 cm. for one hour. In their experience, longer exposures and use of water soaked seed affected germination adversely.

Exposure to powerful electric light during anthesis produced mutations affecting vegetative parts, height of plant, colour of lemma and palea in rice, Sampietro [1937]. Alternate heat and cold treatment can also produce mutations specially polyploids. It is pointed out by Sax [1937] that the polyploid economic plants have largely originated in the tropical regions of high altitudes, in semi-arid regions and in sea coast areas where rapid and extreme changes of temperature occur. At Coimbatore, when rice seed of a pure line three years old kept in cold storage was subjected to a temperature of 50°C. for 15 minutes, a highly sterile tetraploid mutant with a large grain size was obtained, [Sreenivasan, 1940]. Another tetraploid mutant was also obtained when seed of another pure line was kept at a constant temperature of 30°C. for one month. Jones and Longley [1941] found that when rice seedlings were exposed to a temperature of 42°.—45°C., tetraploid cells were found in the root tips. Sakai [1939] has observed disturbances in cell division resulting in mutations in the case of low land rices at temperatures below 15°C. Imai [1938] has recorded a large number of chlorophyll deficient types when germinating seeds of rice were subjected to X-rays. Auto-tetraploid individuals were obtained from the offspring of seedlings treated with chloral hydrate [Ichijima, 1934].

Plastid mutations

Some of the chlorophyll deficient types belong to this category. An example of a plastid mutation (chimera) that had occurred in Coimbatore may be mentioned here. The full purple lemma and green lemma normally occur in separate plants but in one of the hybrid progenies studied at Coimbatore [Ramiah, 1930], a plant was observed in which the purple and green lemma appeared in the same panicle and even in the same branch of the panicle. The phenomenon proved to be a simple chimera. The grains with green lemma in every case behaved on breeding like the grains with purple lemma, indicating that the change involved in the production of pigment over lemma was confined to the epidermal layer and not to hypodermal layer from which ovules and pollen grains were derived.

Anthocyanin mutations

(i) In a cross studied at Coimbatore [Ramiah, 1930], between two types whose characters are mentioned below, an aberrant plant, thought to be a cross-over, was obtained.

Characters	T. 1359	T. 264
Internode	Dark purple, looking black	Ordinary purple lines only
Lemma	Dark purple, looking black	Green
Rice pericarp	Purple	White

The characters of T.1359 were all inherited together and behaved as a simple dominant over those of T.264. Though the purple rice in F_2 was associated with dark internode and lemma, the intensity of colour varied, none approaching that of T.1359. An attempt was made to grade the colour of rice into groups by breeding. Out of thousands of plants examined in F_2s, F_3s and later generations, one aberrant type occurred in F_3 which had the internode and lemma characters of T.1359 but with white rice. No complementary type with the internode and lemma characters of T.264 and with purple rice occurred. Further breeding behaviour indicated it was a mutation. The type could not be fixed at all as the progenies followed up to F_7 always segregated giving the two types, mentioned below.

	Dark purple internode Dark purple lemma	Purple lined internode green lemma
	White rice	White rice
F_4	341	163
F_5 (4 families)	67	36
F_6 (18 families)	1174	712
F_7 (3 families)	162	98

The above segregation represents a 2 : 1 rather than anything else indicating that in the original mutant the homozygous zygote for dark-purple internode and lemma was lethal.

(ii) An interesting mutation for the presence of pigment in the apiculus might be mentioned [Ramiah, 1935]. In an F_3 culture breeding pure for the absence of pigment at the apiculus (the culture had purple pigment at the leaf axil and stigma) a plant with purple apiculus and distinctly earlier in duration than the rest of the plants in the culture appeared. The plant was first suspected to be a natural cross. When bred from, it segregated giving plants with pigmented apiculus and green apiculus approximately in the proportion of 1 : 3 which definitely disproved its hybrid origin. The segregating family consisted of only two groups A and B, corresponding respectively to the parental type and the mutant type :

	Group A Parental type	Group B Mutant type
Mean flowering duration in days	138	112
Mean number of ears per plant	2·1	10.6
Spikelet sterility	Very low	High
Apiculus colour	Green	Purple
Number of individual plants	82	31

All the 31 plants when grown again were found to segregate for several characters. In flowering duration the early group formed about half of the late group. With regard to the number of ears per plant, there was not the sharp distinction as was observed in the original mutant, but all the early plants had a definitely higher mean number of ears than the lates. All the 32 progenies segregated for the presence of pigment at the apiculus and the proportion of the two groups varied very considerably with a mean of 6 pigmented to 1 non-pigmented. There was segregation for various other characters also like awning, size of grain, etc. and the material proved too complicated for analysis. It is definite that the mutation for apiculus colour has involved changes in the chromosomes but the material was unfortunately not examined cytologically.

In the statement attached to the Chapter all the mutations of genetical interest recorded in rice are mentioned except the haploids and polyploids. The genetics of these mutations, wherever it has been studied, has been referred to already in Part III.

Recorded mutations in Rice

Serial No.	Description of mutation	How caused	Genetics and proposed genic symbol	Authority
	Habit of the Plant			
1	Ageotropic or lazy	X-ray mutation	Simple recessive **la**	Ramiah and Parthasarathy [1936]
	Do.	Spontaneous	Do.	Jones [1938, *a*]
	Dwarfing			
2	Normal dwarf	Spontaneous	Simple recessive **d**	Parnell *et al.* [1922], Sugimoto [1922], Akemine [1925], Jones [1933], Ramiah [1933], Nandi and Ganguli [1941]
3	Dwarf Japan I	Do.	Simple recessive $\mathbf{d}_1$	Akemine [1925], Kadam [1937]
4	Dwarf Japan II	Do.	Simple recessive $\mathbf{d}_2$	Kadam [1933]
5	Dwarf Kolamba	Do.	Simple recessive $\mathbf{d}_3$	Do.
6	Dwarf Y 2139	Do.	Simple recessive $\mathbf{d}_4$	Do.
7	Dwarf Bunketuto	Do.	Simple recessive $\mathbf{d}_5$	Do.
8	Dwarf	Do.	Double recessive $\mathbf{d}_1$ $\mathbf{d}_2$	Akemine [1926]
9	Dwarf with tip awns	X-ray mutation		Ramiah and Parthasarathy [1938]
10	Dwarf with small grains	Spontaneous in a hybrid culture	Trisomic	Mad. Agri. Stat. Reports, Paddy Breeding Station. 1936-37
11	Dwarf with narrow leaf	Do.	Do.	

Recorded mutations in rice—contd.

Serial No.	Description of mutation	How caused	Genetics and proposed genic symbol	Authority
	Chlorophyll deficiencies			
12	Albino	X-ray mutation	Simple recessive $\mathbf{w}$	Ramiah and Parthasarathy [1938]
13	Do.	Spontaneous	Double recessive $\mathbf{w_1\ w_2}$	Morinaga [1927]
14	Do.	Do.	Triple recessive $\mathbf{w_1\ w_2\ w_3}$	Codd [1934]
15	Do.	Do.	Complementary genes $\mathbf{w_a\ w_b}$	Morinaga [1932]
16	Do.	Do.	Abnormal ratios	Ramiah and Ramanujam [1935]
17	Do.	X-ray mutation	Do.	Ramiah and Parthasarathy [1938]
18	Albino with coleoptile yellow	Do.	Do.	Do.
19	Lethal yellow	Spontaneous mutation	Simple recessive $\mathbf{y}$	Kasahara [1934], Ramiah and Ramanujam [1935], Imai (1935), and **Kadam** [1941]
20	Do.	X-ray mutation	Do.	Ramiah and Parthasarathy [1938]
21	Do.	Spontaneous	Double recessive $\mathbf{y_1\ y_2}$	Kadam [1941]
22	Lethal yellow with green sheath	X-ray mutation		Ramiah and Parthasarathy [1938]
	Zebra marked			
23	Zebra yellow (lethal)	Spontaneous mutation	Simple recessive $\mathbf{zy}$	Ramiah and Ramanujam [1935]
24	Do.	X-ray mutation	Do.	Ramiah and Parthasarathy [1938]
25	Zebra white	Do.	Do. $\mathbf{zw}$	Do
26	Do.	Spontaneous mutation	Complementary genes $\mathbf{zw_1\ zw_2}$	Kadam [1939]
27	Stunted yellow	Do.		Kadam [1941]
28	Tip brown yellow	Do.	Complementary gene $\mathbf{tpa\ tpb}$	Kadam [1941]

29	White virescent from K—70	Spontaneous mutation	Designated V_1—V_8	Kadam [1941]
30	Light green virescent	Do. from hybrid culture		Do.
31	Golden yellow virescent	Do.		Do.
32	Yellow virescent	Spontaneous mutation	Simple recessive **v**	Ramiah and Ramanujam [1935]
33	Do.	X-ray mutation	Do.	Ramiah and Parthasarathy [1938]
34	Do.	Spontaneous mutation	Double recessive v_1 v_2	Ramiah and Ramanujam [1935]
35	Do.	X-ray mutation	Do.	Ramiah and Parthasarathy [1938]
36	Virescent (white allele)	Spontaneous mutation	Simple recessive vj_1 v_8	Kadam [1941]
37	Virescent (linked)	Do.	Simple recessive	Jodan [1941]
	Striped patterns			
38	Green and white	Do.	Simple recessive **vr**	Ramiah and Ramanujam [1945]
39	Do.	X-ray mutation	Do.	Ramiah and Parthasarathy [1938]
40	Do. plant dwarf sterile	Do.	Do.	Morinaga [1932]
41	Green and white persistent	Spontaneous mutation	Do.	Pal and Ramanujam [1941]
42	Green and yellow	Do.	Do.	Ramiah and Ramanujam [1935]
43	Do.	X-ray mutation	Do.	Ramiah and Parthasarathy [1938]
44	Blotched white	Do.	Do. **vrb**	Do.
	Non Mendelian chlorophyll deficiencies			
45	Green and white variegation	Spontaneous mutation	Plastid mutation	Imai [1928] Ramiah and Ramanujam [1935]
46	Green and yellow fading	Do.	Do.	Morinaga and Kondo [1932] Ramiah and Ramanujam [1935].
47	Green and yellow persistent	Do.	Do.	Ramiah and Ramanujam [1935]
48	Albino	Do.	Do.	Pal and Ramanujam [1941]
49	Variable green and white	Do.	Do.	Imai [1928]

Recorded mutations in rice—contd.

Serial No.	Description of mutation	How caused	Genetics and proposed genic symbol.	Authority
	Leaf blade			
50	Rolled leaf low fertility	X-ray mutation	Double recessive **lro_1 lro_2**	Ramiah and Parthasarathy [1938]
51	Rolled leaf fertile	Spontaneous mutation	Simple recessive	Nagai [1926]
52	Rolled leaf sterile			
53	Narrow leaf	X-ray mutation	Simple recessive **ln**	Ramiah and Parthasarathy [1938]
54	Narrow leaf open lemma	Spontaneous mutation	Do. **lnl**	Isshiki [1933]
55	Twisted leaf low fertility	Do.	Do. **ltw**	Do.
56	Twisted leaf pale green	Do.	Do.	Do.
57	Narrow leaf malformed spikelet sparsely arranged.	X-ray mutation	..	Ramiah and Parthasarathy [1938]
58	Liguleless	Spontaneous mutation	Simple recessive **lg**	Jones [1933], Chiapelli [1936] and Paiacco [1938]
59	Auricleless	Do.	Simple recessive **aw**	
	Panicle			
60	Erect slender spindly	Do.	Simple recessive	Kondo [1927]
61	Stiff, malformed reduced floral-parts	X-ray mutation	Do.	Ramiah and Parthasarathy [1938]
62	Malformed rudimentary spikelets	Do.	..	Do.
63	Sparse spikelet arrangement (rolled leaf)	Do.	..	Do.
64	Dwarf with reduced emergence	Do.	..	Do.
65	Reduced panicle sterile	Do.	..	Do.

	Glume			
66	Long glume	Spontaneous mutation		Kadam [1942]
	Lemma-palea			
67	Beaked and slender grain	X-ray mutation		Ramiah and Parthasarathy [1938]
68	Glume deformed, lemma-palea absent	Do.		Do.
69	Ill-formed grain with rudimentary spikelets.	Do.		Do.
70	Purple apiculus	Do.		Do.
71	Brown wash	Do.		Do.
72	Ripening streak brown	Do.		Do.
	Awning			
73	Tip awns	Do.		Do.
74	Full awns	Do.		Do.
	Grain size			
75	Long narrow grain	Do.		Do.
76	Elongated grain	Do.		Do.
77	Small grain	Spontaneous mutation	Simple recessive	Terao [1928]
	Sterility			
78	Complete sterile	Do.	Simple recessive **fo**	Sugimoto [1923]
79	Paleaceous sterile	Do.	Do. **fp**	Nagai [1926]
80	Barren sterile	Do.	Do. **fb**	Anandan and Krishnaswamy [1934]
81	Barren sterile with long flag leaf and reduced florets.	X-ray mutation	Double recessive $\mathbf{fb}_1$ $\mathbf{fb}_2$	Ramiah and Parthasarathy [1938]
82	Sterile tip or sponginess	Do.	Simple recessive **fw**	Do

Recorded mutations in rice—contd.

Serial No.	Descrition of mutation	How caused	Genetics and proposed genic symbol.	Authority.
83	Male sterile	Spontaneous mutation	Simple recessive **fm**	Ishikawa [1929], Kadam [1932], Ramanujam [1935], Miyazawa [1935], and Sreenivasan [1937]
84	Awned sterile	Do.	Do. **fan**	Nagai [1926]
85	Staminodal sterile	Do.	Do. **fst**	Nagai [1926]
86	Pistillate sterile	Do.	Do. **ffs**	Miyazawa [1935]
87	Asynaptic sterile	Do.	Complementary genes **fasa fasb**	Ramanujam and Parthasarathy [1935]
88	Partial sterile	Do.	Simple recessive **fs** gene unstable giving reverse mutation	Ishikawa [1927]
89	Slender semi-sterile	Do.	Simple recessive **fs1**	Miyazawa [1935]
90	Sterile shrivelled stamens	Do.	Do. **fsh**	Do.
91	Semi-sterile, large grained	Do.	Do.	Kagawa [1939] and Kondo [1941]
92	Sterile, open lemma	Do.	Do.	Miyazawa [1932]
93	Sterile, beaked	X-ray mutation	Simple recessive primary trisomic.	Ramiah and Parthasarathy [1938]
94	Semi-sterile, ever-splitting	Spontaneous mutation	Sex-linked lethal	Terao [1921]
95	Semi-sterile	X-ray mutation	Mutation due to interchange of segments of non-homologous chromosomes	Ramiah and Parthasarathy [1938]
96	Sterile stumpy	Do.	Secondary trisomic	Do.

CHAPTER XVIII

CYTOLOGY OF RICE AND WILD RICES

CYTOLOGY may be defined as 'that branch of biology which treats of the organization of protoplasm, usually in the form of cells, and the relation of alterations in this organization to such phenomenon as growth, differentiation and heredity'. The study of cytology has made rapid strides in recent years and has contributed largely to the rapid advancement in the study of genetics. The chromosome theory and the parallellism of gamete formation with the distribution of hereditary characters as observed in Mendelian segregation is one of the greatest of achievements in biology. The rapid strides which cytology has made during recent years has enabled scientists to examine a number of genetic problems from this aspect, and an applied branch of cytology, 'cytogenetics', is fast developing.

1. CYTOLOGY OF RICE

The first report on chromosome numbers in cultivated rice was made by Kuwada [1910] and he found the haploid number to be twelve and diploid twentyfour. Several investigators have later confirmed the above in several cultivated rices. Up to 1930, no chromosomal mutants with either more or less number of chromosomes, than the typical number were reported. Several workers have since studied the micro and macrosporogenesis of rice very thoroughly, which has become possible with the advance in cytological technique. Only a brief summary of their work is given here, and for more details the original papers may be consulted.

Observation in the somatic cells. Kuwada observed that the chromosomes in the somatic cells were paired, but the degree of such pairing was variable and Parthasarathy [1938, b] observed 10 pairs and four single chromosomes. At somatic prophase two chromosomes with terminal knob-like bodies remained attached to the single nucleolus, and if two nucleoli were present, each of this was attached to a particular separate chromosome by terminal enlargement of the knob. According to Nandi [1937], nucleolus may be regarded as a compound product consisting of substances from all the chromosomes and hence perhaps of all the genes and since it was present universally in all organisms and is perpetuated from cell generation to cell generation, it might have a role in inheritance. The nucleolus in rice has also been studied by others. Selim [1930] was of the opinion that the races of rice could be grouped according to the number of nucleoli (one or two) and their behaviour. It was also suggested that where division of nucleoli took place, the primary one contributed to the formation of the spindle and the secondary one to chromosome formation. Hedayetullah [1933] found that when one variety in which the pollen had two large nucleloli of equal size was crossed with another variety with two uneuqal nucleoli, it gave invariably hybrids with two unequal nucleoli in the pollen mother cells. Heitz [quoted by Parthasarathy 1938, b] was of the opinion that the number of satellites must always correspond to the number of haploid complements in the species.

Parthasarathy [*loc. cit.*] making a detailed study of the number and volume of nucleoli, found that there were varieties with two and others with

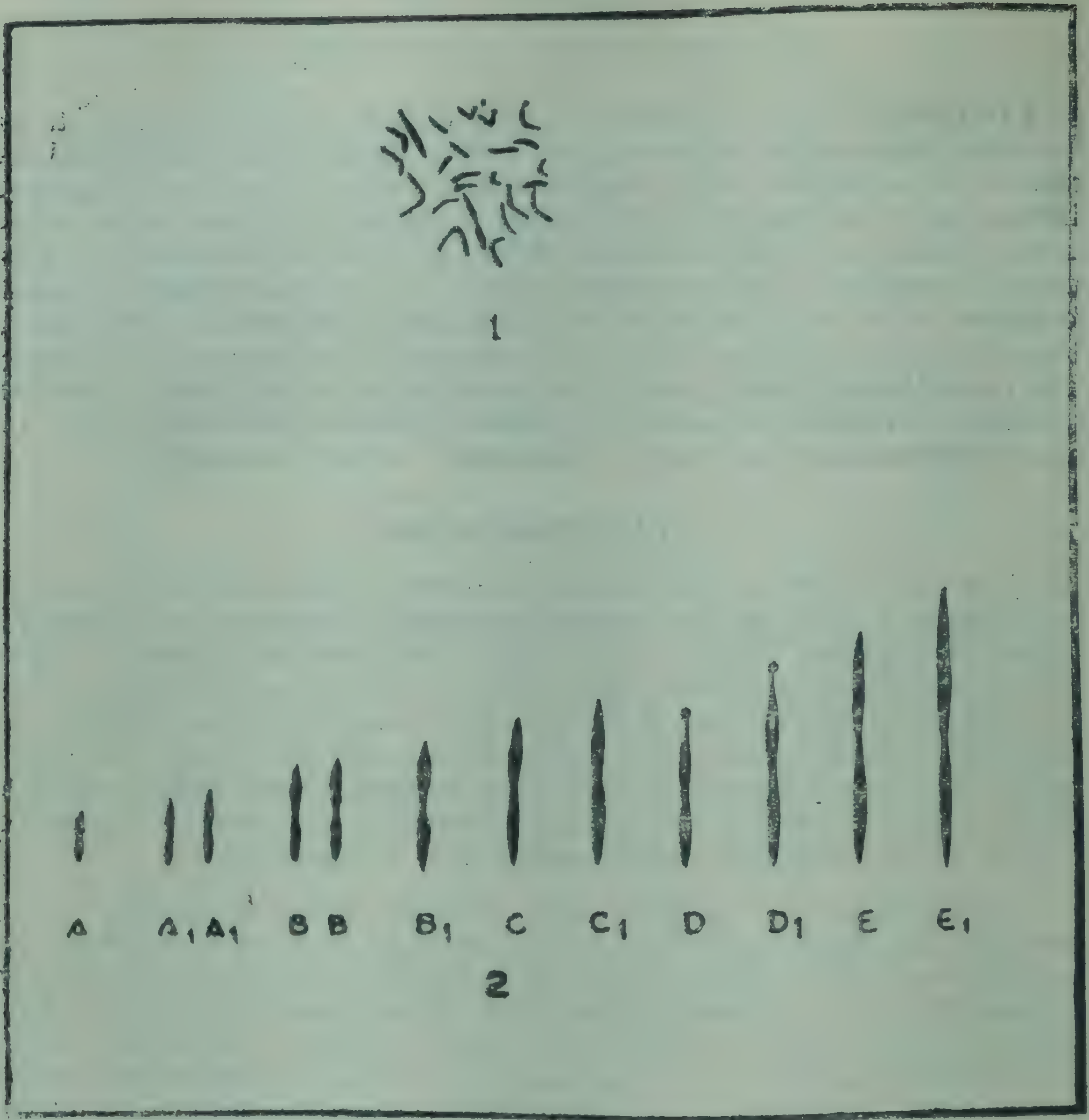


Fig. 6 Somatic metaphase

(After Nandi 1936)

1. Somatic metaphase from root tip (x 3200)
2. Haploid genome indicating the two sets of chromosomes from the two **five-paired species** with **duplication of one chromosome in each set,**

four nucleoli and thus pointed out the limitations to the general rule that the number of nucleoli was in direct proportion to the number of haploid complements present in the genome. In rice, Ramanujam [1937, a] has shown that a mutation leading to the inactivation of the nuclear body or the loss of the satellite in varieties with four nucleoli will give in subsequent generations varieties with four and two nucleoli. That this was possible is shown by the existence of two and four nucleoli in *japonica* and *indica* groups of rice respectively. In certain other preparations, Nandi [*loc. cit.*] was able to find two pairs of satellited chromosomes, the satellited pair being attached by a slender thread to the proximal end of the chromosomes. The presence of the satellites and their number appear to have a bearing on the basic number of chromosomes.

Meiosis. The resting nucleus of the pollen mother cells generally has a single nucleolus with no crystalline bodies. The chiasmata formation in the pollen mother cells which may be regarded as the obvious cytological evidence of crossing over between chromosomes was studied in detail by Nandi [*loc. cit.*] at diakinesis, and he found that the interstitial chiasmata were very frequent at early diakinesis and the frequencies fell off rapidly until metaphase I. As meiosis proceeds, the total number of chiasmata decreases, but the proportion of chiasmata that are terminal increases. These studies have shown that the number of chiasmata, as Darlington suggests, varies with the length of chromosomes. The highest number observed in the longest bivalent of rice at diaknesis was three and the smallest number was one in the small chromosomes. Nandi also observed the phenomena of cytomyxsis, pollen mother cell fusion, binucleate and tertraploid pollen mother cells and failure of cytokinesis during the meiotic divisions of some of the microsporocytes, and these were believed to give rise to diploid gametes which would account for the origin of triploid and tetraploid plants in rice. Similar observations were also later recorded by Ramanujam [1938].

Chromosome morphology. From a large number of metaphase plates the characteristic morphology of somatic chromosomes and their size relations were studied by Nandi [1936, b]. It was possible to classify the 24 chromosomes into ten types. As shown in Fig. 6, the ten types of chromosomes fall into two groups of five each, there being one exactly similar chromosome in each group. The members of these two groups are designated : A, BB, C, D, E and A_1 A_1, B_1, C_1; D_1, E_1. It is evident that A is definitely shorter than A_1 A_1, B_1 is slightly longer than BB. There is very little difference between C and C_1. D with a satellite is definitely shorter than D_1 also with a satellite. E_1 is distinctly longer than E. It is also quite obvious that A_1 and B_1 occur twice. They could be distinctly grouped into (1) largest pair of chromosomes with medium constrictions, (2) medium sized chromosomes with medial insertion region and (3) small chromosomes. Sethi [1937] studied cytologically a large number of rice varieties and grouped the somatic complement generally into five large, four medium and three small pairs. Rau [1929] had recorded that the largest chromosome was double the small one in size and Sethi found that the largest measured 2.1μ, while the smallest $1.4\ \mu$ Ramanujam records that sizes varied from 0.7μ to 2.8μ. Recently Phatak [1940] has shown that four pairs have medium constrictions and the rest submedian and subterminal primary constrictions.

Secondary association. This was first observed by Kuwada [*loc. cit.*] at the metaphase where bivalents were found to be associated in pairs. In his meiotic study of pollen mother cells, Sakai [1935] could observe in normal diploids, firstly, quadrivalent association in diakinesis and metaphase I, and secondly very frequent secondary association of meiotic chromosomes, for instance, the formation of two groups of three and three groups of two. On the basis of such results the author came to the conclusion that 12 was not the basic number in the strict sense, but 5 was the primary one, from which 12 had been derived. The maximum association that was observed by Nandi was three groups of two chromosomes and two-groups of three chromosomes. No six groups of two bivalents secondarily associated were ever observed. These observations were confirmed later by Ramanujam [1938] and Parthasarathy [1938, b]. Yamura [1933] suggested that the origin of *Oryza* might be due to the hybridisation between 5 and 7 chromosome species. An indirect evidence to show that rice was not a normal diploid is the presence of polymeric genes controlling certain characters. Autosyndesis in the chromosomes is another factor adding support to this view. The cytological data gathered from the observations made by Nandi and Ramanujam on the normal diploid rices, triploids and some inter-specific crosses add support to the genitical evidence that rice is polyploid in nature. The ten morphological groups of the somatic chromosomes indicate that the 'haploid' genome of the cultivated rice is made up of two original five paired species belonging to two different ancestral genomes in which two chromosomes were duplicated.

A hypothesis about the possible course of events in the evolution of *O. sativa* has been suggested by Nandi [1936, b]. It might be supposed that the original species with a haploid set of 5 chromosomes A, B, C, D and E, respectively produced by structural changes another species whose chromosomes would be A_1, B_1, C_1, D_1 and E_1. A cross between these two species was likely to be sterile. Under such circumstances it was conceivable that variable aneuploid gametes with n = 6 arose through meiotic irregularities in a cross between the two species concerned, and then gave a plant with 12 chromosomes which could have some such formula as shown below which was not very different from what has been suggested by Sakai [1935].

A	A_1	A_1	
B		B_1B	
C		C_1	
D		D_1	
E		E_1	n=12

Chromosome doubling either somatically or gametically could produce a secondarily balanced allotetraploid with 2n = 24. It would be fertile, vigorous and constant through autosyndesis. The conclusion that one chromosome (A_1) from one ancestral group and another (B) from another group are duplicated is confirmed by the observation of one or two bivalents [Morinaga and Fakushima, 1934] in the haploid plants of rice and quadrivalents in the (apparently) diploid rice by Nandi [1936, b]. On this basis, a hexavalent must be present in triploid form and Ramanujam [1937, a] had actually obtained a hexavalent in cytological investigations of a triploid plant. The immediate wild progenitor of *O. sativa* with the basic number of five chromosomes has not yet been traced and is probably extinct. However, it does not preclude the possibility that the nearest wild relative of the cultivated rice, *O. sativa* var. *spontanea* might have greater affinities to the original descendant from the extinet species.

Cytology of wild species of rice

More recently cytological investigations of a large number of species of *Oryza* have been made and results regarding their probable relationship recorded. These are now dealt with briefly. The somatic chromosomes in them are reproduced in Fig. 7.

O. glaberrima. This species largely cultivated in Africa, very similar to *O. sativa* in morphological characters, and which crosses very easily with *O. sativa,* has been studied by Ramanujam [1938]. The chromosome complement is similar to that of *O. sativa* (2n = 24); at meiosis, the chromosomes form 12 bivalents in P.M.C. and separate regularly. Secondary association at metaphase I gave the maximum frequency of 5 (3 of 2 and 2 of 3) as in *O. sativa.*

O. officinalis. A perennial species propagated by root stock; this wild rice is common in parts of Burma, Malaya and portions of Assam and has affinities to *O. minuta* in habit and nature of grain. The number of somatic chromosomes is twentyfour, and they are found to be slightly larger in size than those of *O. sativa* [Ramanujam 1938 and Nandi 1938]. Analysis of the chromosome morphology recorded by Nandi [1936, b] showed the same types of chromosomes as in *O. sativa,* i.e. 8 types are present twice and 2 types four times making 2n = 24. Twelve bivalents with marked degree of secondary association were noticed at metaphase I; the two divisions were regular and normal spores were generally formed. Successful cross with *O. sativa* has been reported.

O. longistaminata. This is also a perennial wild species propagated by rhizomes, first obtained from West Africa. It resembles very closely *O. barthii* and its somatic number is 24 [Ramanujam, 1938]. Forms apparently *O. longistaminata* have since been found in parts of India also. Crosses between *O. longistaminata* and *O. sativa* have been obtained at Coimbatore.

O. latifolia. Two forms appear to exist in this species. The one from Cuba has 48 somatic chromosomes and the sample from Malaya has 24 only [Jones and Longley 1941]. The Cuban form is more vigorous and has larger culms, leaves and panicles and somewhat larger seeds than the Asian form. The species shows regular divisions and it sets seed freely.

O. minuta. This species resembles *O. officinalis* a great deal though its parts are smaller. It ripens quickly after it flowers and appears to cross-pollinate freely as the stamens are exserted entirely. A number of workers have found this species to be a form with 2n = 48. The somatic chromosomes are of two different sizes, composed of 12 pairs of small bivalents and 12 pairs of large ones. From a study of the morphology of the haploid genome, Nandi [1938] found that there are ten types of chromosomes of two different sizes, eight being represented twice and two four times. Thus the chromosome complement of *O. minuta* does not represent reduplication

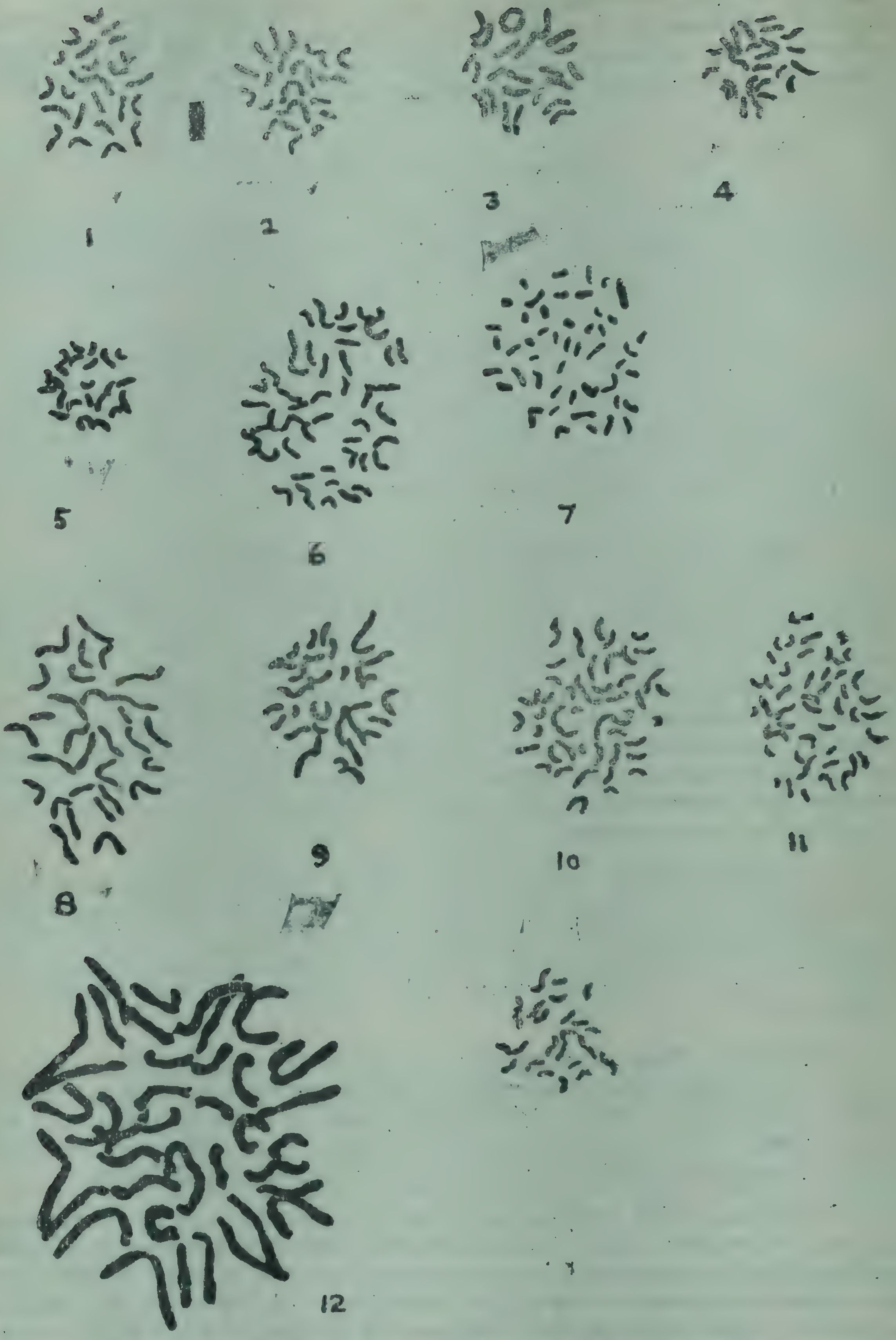


FIG. 7 Chromosome of rice, cultivated and wild species

1. *O. sativa*
2. *O. glaberrima*
3. *O. officinalis*
4. *O. longistaminata*
5. *O. barthii*
6. *O. minuta*
7. *O. coarctata*
8. *Zizania aquatica*
9. *Zizania latifolia*
10. *Leersia oryzoides*
11. *Leersia hexandra*
12. *Lygeum spartum*
13. *Hygrorhiza aristata*

of a basic set. It has been shown by Nandi from other studies also that *O. minuta* is a distinct, stable and fertile species which should have originated as an amphidiploid from a sterile diploid hybrid between *O. sativa* and *O. officinalis,* followed by chromosome doubling.

A study of meiosis of this species has also been made by the same author. At diakinesis 24 bivalents of different sizes and shapes of which four are attached to the nucleus, are formed. Sufficient cells were not available to count the maximum type of secondary association but a few associations with three bivalents were observable.

O. coarctata Roxb. This is a wild species natural to the coastal regions of Sind and Bengal in India and evidently thrives well under saline conditions. It tillers more profusely than other wild rices of India, more erect and tall growing. The grain is coarse, hardly looking like rice and does not shed so completely as the other wild forms. It has never been possible to propagate this species from seed. Parthasarathy [1938] has shown it to be a tetraploid (2n = 48) or a secondarily balanced octoploid. The chromosomes are small like those of *O. sativa* and no satellites are visible. Four nucleoli are formed at somatic telophase which indicates that four satellited chromosomes are present in the complement.

O. echingeri Peter. This wild species of *Oryza* found in Tanganyka possesses 48 somatic chromosomes [Phatak, 1940]. Eight nucleoli are found in telophase and eight SAT-chromosomes attached to the nucleolus at prophase. This species appears to be an amphidiploid derived from a cross between two species of *Oryza* each with 4 nucleoli

O. sylyestris Stapf. This is again found to be a secondary balanced actoploid (2n = 48) with eight nucleoli [Phatak, 1940].

No detailed examination of the other species of *Oryza* has yet been made although chromosome number has been determined in *O. cubensis* (Gotoh), *O. formosana, O. subulata* and *O. granulata*; all of them possess 12 pairs of somatic chromosomes.

2. INTERSPECIFIC HYBRIDS AND THEIR CYTOLOGY

The expeditions of the Russian School of Botanists to different parts of the world, in search of new genes in wild species related to cultivated crops, have given a new orientation to the breeding of crop plants. These wild species are found to carry valuable genes worth transferring to cultivated forms. Through the use of wide crosses scientists abroad have been able to produce some valuable strains. Interspecific hybridisation, besides offering a means of determining the relationship and origin of the different species of a genus, is also helpful to produce chromosomal variation leading to fixation of new types of economic value. But one of the greatest difficulties in making use of species crosses has been the enormous sterility in the succeeding generations. Besides sterility, the desired combinations in the F_2 generations are not realised due to powerful restrictions to character recombination such as, gametic and zygotic elimination, pleiotropy and linkage [Anderson, 1939].

Some interspecific crosses have, however, been attempted between cultivated and wild rices. Of a large number of crosses tried in Madras and

Bengal only a few were successful; most of them did not even set seed. The following summary shows the successful crosses reported in rice literature so far [Jones and Longley 1941].

Cross	Somatic chromosome numbers
O. sativa × **O. officinalis* (Asia)	24 × 24 Ramiah [1934]
O. sativa × *O. latifolia* (Cuba)	24 × 48 Gotoh [1935]
O. latifolia (Cuba) × *O. sativa*	48 × 24 Morinaga and Aoki [1938, *a*]
O. sativa × *O. glaberrima*	24 × 24 Ramiah [1938]
O. sativa × *O. officinalis*	24 × 24 Ramanujam [1937, *b*]
O. sativa × *O. officinalis*	24 × 24 Nandi [1938]
O. sativa × *O. cubensis*	24 × 24 Gotoh and others [1935]
O. sativa × *O. minuta*	24 × 48 Morinaga [1934]
O. minuta × *O. sativa*	48 × 24 Nandi (1938] Morinaga and Aoki [1938, *a*]
O. minuta × *O. officinalis*	48 × 24 Nandi [1938]
O. minuta × *O. latifolia* (Cuba)	48 × 48 Morinaga and Aoki [1938, *a*]
O. sativa × *O. longistaminata*	24 × 24 Ramiah [1928]
F_1 (*O. sativa* × *O. officinalis*) × *O. eichingeri*	(24 × 24) × 48 Srinivasan *et. al.* [1941]

* This *O. officinalis* was first described at Coimbatore as *O. latifolia* by mistake.

In most of these crosses the F_1 was highly sterile without any fruit formation. A few cases have been recorded where there was slight setting when the F_1 was backcrossed to one of the parents. Morinaga and Aoki [1938, a] have shown that certain cultivated varieties cross more readily with wild rice than others. The sterile interspecies hybrids in other crops are sometimes made fertile by doubling their chromosomes by colchicine treatment. In some cases as in cotton, the sterile interspecies hybrid between the diploid and the tetraploid sets seed when it is crossed to the tetraploid. Owing to the almost complete sterility in the F_1 it has not been possible to make any further progress with the interspecies hybrids. Attempts to make such hybrids fertile have so far not succeeded. A large number of crosses with the *O. sativa* var. *spontanea* (=*fatua*) has been studied in China and a valuable variety with vigorous growth, resistant to cold and soil acidity is reported to have been produced. But there is no difficulty about sterility in *O. sativa* × *O. sativa* var. *spontanea*.

When two parents differing in chromosome numbers or in chromosome make up, constituting different genomes, are crossed there is a great deal of irregularities in the chromosome behaviour of the resulting F_1. Information available on some of these crosses is dealt with below:

O. sativa ($2n=24$) × *O. officinalis* ($2n=24$). This was studied by Nandi [1936-38] in great detail. The cross was successful when *O. sativa* was used as the female parent. The F_1 of this cross looked phenotypically more like *sativa* parent. Anthers were smaller and contained only shrivelled pollen grains; backcrosses of the F_1 plants with *O. sativa* as well as with *O. officinalis* were failures. Hence no further progenies could be studied.

The chromosomes in *O. officinalis* are larger in size than those of *O. sativa.* Thus structural differences are in part responsible for the differentiation of this species from *O. sativa* and hence crosses between them rarely succeed, and if they do, there is great amount of sterility due to the non-pairing of chromosomes at meiosis in the F_1. At the diakinesis of the meiotic division of F_1, there were only 24 univalents, 12 large and 12 small, corresponding to those of *O. officinalis* and *O. sativa* respectively without any pairing. In the absence of bivalents meiosis could not proceed normally and the irregularities in the next division resulted in degeneration of microspores of varying size and number. Working on the same inter-specific cross, Ramanujam [1937, b] confirmed the observations of Nandi in the main. There was a significant difference in the total length of the chromosomes of the diploid set in parental species, the total length of the *officinalis* chromosomes being one-third longer than that of the *sativa* chromosomes and the total length of the hybrid chromosomes was nearly equal to that of the *officinalis* (Plate XXIX). He came to the conclusion that the change of length observed in the hybrid is a proof that the length of chromosome is controlled by the genotype. He, however, observed a few cells with loosely paired, bivalents and it is probable that in hybrids with weak affinity between chromosomes, external influences play a greater part in affecting conjugation than in pure species as is observed by Morinaga in *Brassica.* When a few spikelets of the F hybrid were backcrossed to *O. sativa,* the resulting progenies turned out to be triploids and this would suggest that certain pollen mother cells give rise to functional diploid gametes by a regular division of the univalents twice.

O. minuta ($2n = 48$) × *O. officinalis* ($2n = 24$) and *O. minuta* ($2n = 48$) × *O. sativa* ($2n = 24$). In these crosses studied by Nandi [1936-38] the meiotic division was found to be very irregular and at metaphase I, twelve bivalents were generally present, trivalents and quadrivalents were not found at all. In the F_1 of *O. minuta* × *O. officinalis* with 36 chromosomes, it was found that 12 bivalents were larger, there being no difference in size and shape between members of each pair. This would suggest that the pairing of chromosomes is autosyndetic and consequently, the 24 chromosomes (12 bivalents) are derived from the 12 homologues of the haploid *officinalis* genome in *minuta* and the 12 chromosomes of *officinalis.* The rest of the 12 univalents in the hybrid were smaller and belong to another set.

Again in the hybrid *O. minuta* × *O. sativa* with 36 chromosomes it is seen that 12 bivalents are similar, the two homologues of each bivalent pair being of similar shape and size. The other univalents are larger and probably belong to a different set. Thus the 12 small chromosomes of original *O. sativa* have found 12 homologues of the *O. sativa* genome in *O. minuta* and formed pairs by autosyndetic action.

It was found that conjugation of the chromosomes in either hybrid never occurred between small and large ones, but always only between small ones. That these hybrids did not contain more than two similar chromosomes is evident from the absence of trivalents or multivalents. Thus *O. minuta* is evidently an allopolyploid (modified octoploid) which must have been formed by natural hybridisation between *O. sativa* and *O. officinalis.* Okura [1937] examining the meiotic division in F_1 hybrid between *O. sativa* and *O. minuta* observed the modal chromosome associations to be 12 bivalents and hence considered that one of the two genomes of *O. minuta* is homologous to the genome of *O. sativa.* Morinaga and Aoki [1938] on the other hand found that during the microsporogenesis, the F_1 of the cross between *O. sativa* and *O. minuta* formed mostly 36 univalents, and bivalents only very rarely and they therefore suggested that the genomes of *O. sativa* bore little relationship with those of *O. minuta.* Though pairing is an indication of homology, absence of pairing need not necessarily mean absence of homology, e.g. asynapsis due to gene action.

O. minuta ($2 = 48$) × *O. latifolia* Desv. ($2n = 24$). Morinaga and Aoki [1938, b] obtained a successful F_1 which showed 36 chromosomes, comprising of both univalents and bivalents at diakinesis. The authors therefore tentatively suggest that *O. minuta* must have one genome in common with *O. latifolia.*

O. sativa ($2n = 24$) × *O. cubensis* ($2n = 24$). This cross was made by some Japanese workers and later by Jones and Longley [1941]. The F_1 plants were sterile and no cytological examination was, however, made. The F_1 plants when backcrossed to *O. sativa,* however, set some seed.

O. sativa ($2n = 24$) × *O. officinalis* ($2n = 24$) × *O. eichingeri* ($2n = 48$). A trispecific hybrid was obtained by crossing the F_1 sterile hybrid (*O. sativa* × *O. officinalis*) with *O. eichingeri* ($2n = 48$) [Srinivasan *et al.* 1941] (Plate XXX). Root tips, of the new hybrid examined gave $2n = 48$ and as the hybird F_1 is known to produce unreduced diploid gametes, the composition of the genomes of this new hybrid is supposed to be 12 *sativa* + 12 *officinalis* + 24 *eichingeri.* This hybrid is also sterile completely and attempts are being made to restore fertility by subjecting the shoots of the sterile hybrid to the action of colchicine.

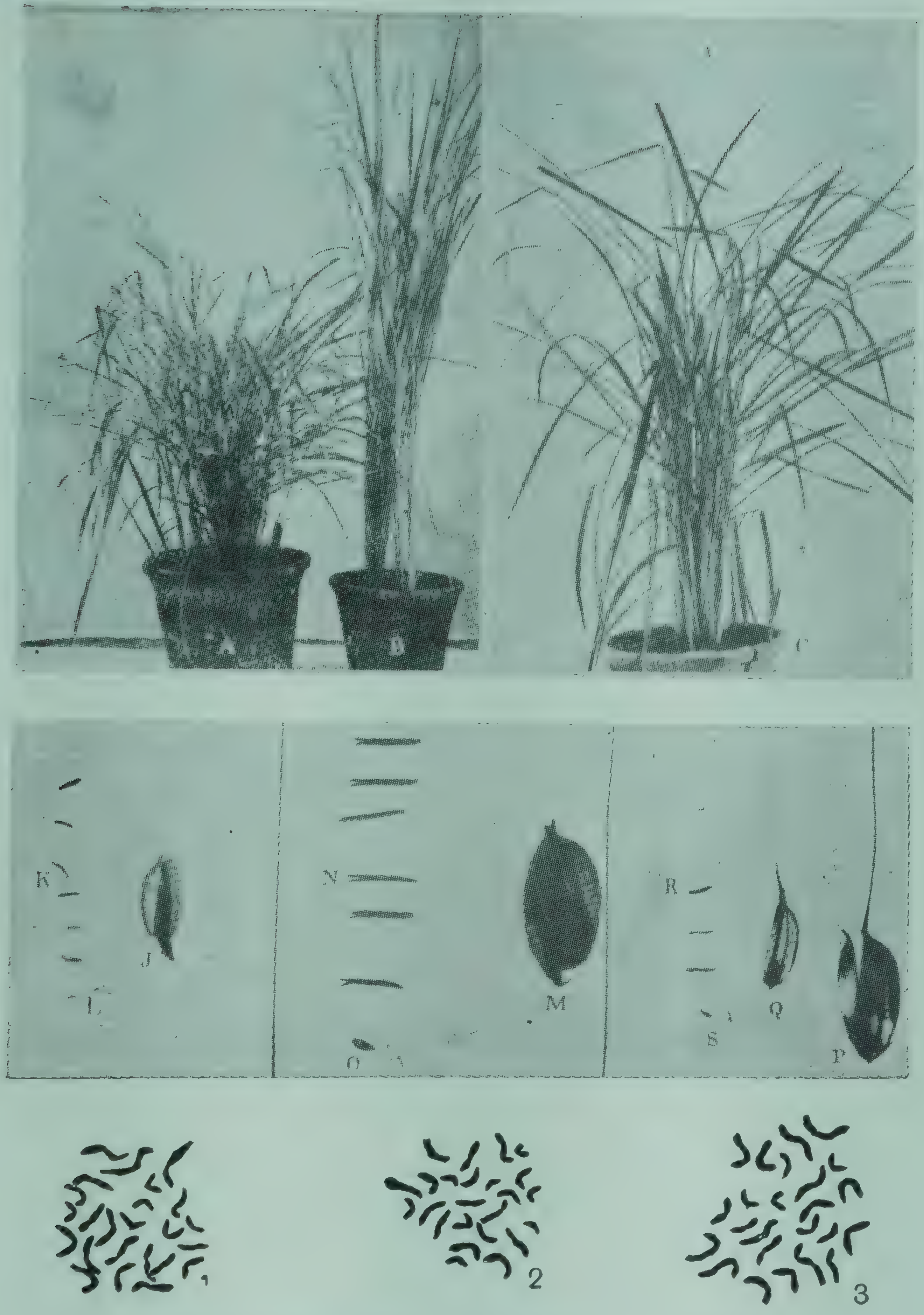
O. sativa ($2n = 24$) × *O. latifolia Desv.* ($2n = 48$). This cross was reported by Gotoh and Okura [1935] and Morinaga and Aoki [1938]. In the F_1 36 univalents were formed and the hybrid was also sterile showing that the species have no genomes in common.

Other interspecific hybrids which were, however, fertile or partly fertile were those between *O. sativa* × *O. glaberrima* and *O. sativa* × *O. longistaminata* reported from Coimbatore. No cytological studies of these hybrids, have, however, been recorded.

3. HAPLOIDS, POLYPLOIDS AND POLYSOMICS IN RICE

The enormous potentialities of polyploidy in producing new types of plants superior to the existing ones has stimulated, since the past two decades, research on polyploidy, its mode of occurrence in nature and its production by artificial means. The occurrence of polyploids is now known to be a common feature in the experimental cultures of several workers.

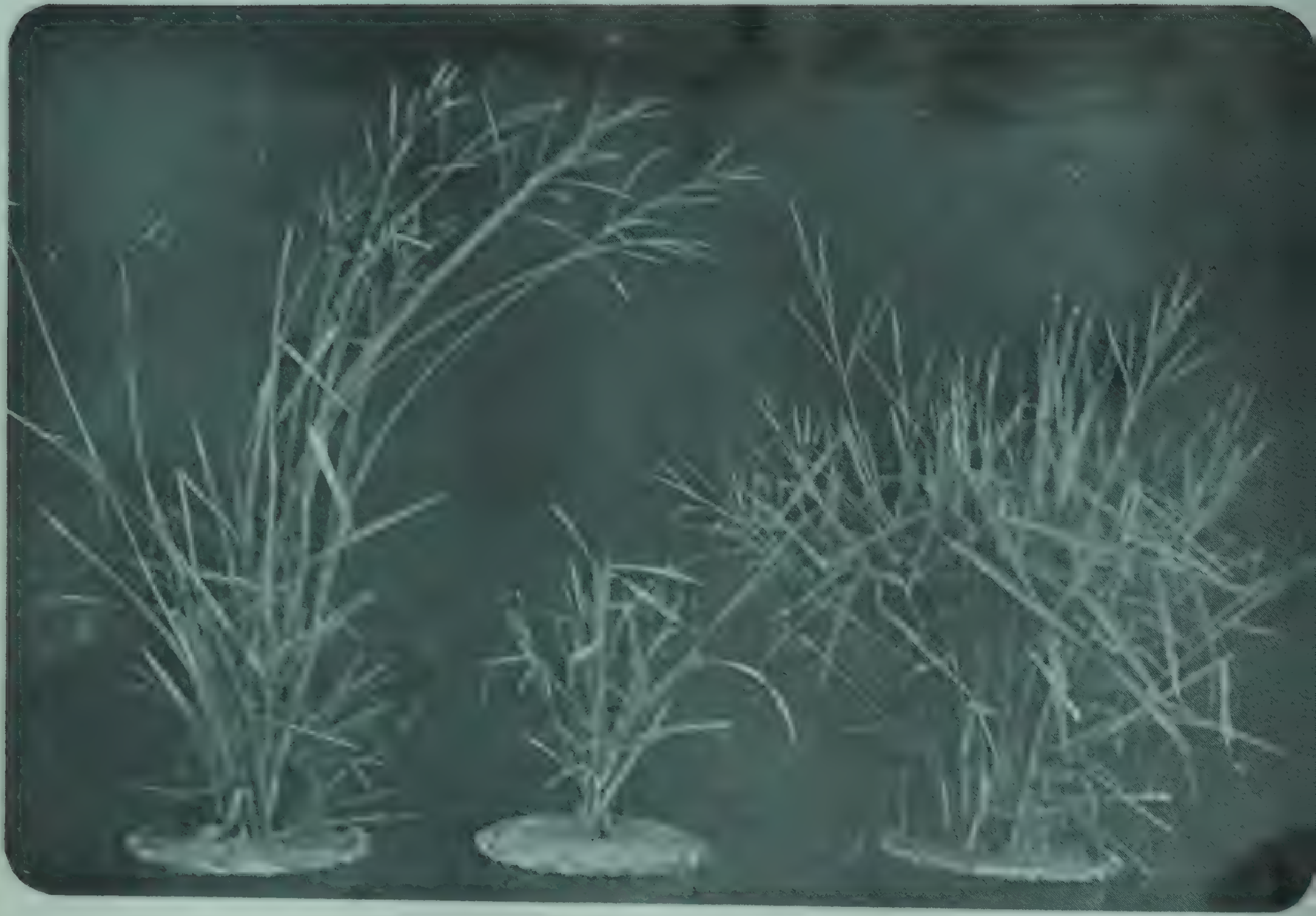
Cytological studies in some crop plants have disclosed that polyploids, specially the allopolyploids, have played an important role in evolution and the production of new varieties and species of economic importance. This is supported not only by the fact that several new artificial species have



Interspecific hybrid : O. officinalis x O. sativa

A. O. officinalis ; B. O. sativa; C. F$_1$ hybrid.
J. Spikelet. K. anthers. L. gynæcium O. officinalis.
M. ,, N. ,, O. ,, O. sativa.
P. Q. ,, R. ,, S. ,, F$_1$ hybrid.
1. Somatic chromosomes O. officinals.
2. ,, O. sativa.
3. ,, F$_1$ hybrid.

(After Ramanujam 1937 b.)



Trispecific hybrid vigorous cut sterile (coimbatur)

1. O. eichingeri.

2. F_1 (O. sativa x O. officinalis)

3. F_1 (O. sativa x O. officinalis)
O. eichingeri.

been produced but also by the experimental synthesis of anatural species. The importance of alloploidy lies in the fact that it transforms sterile species hybrids into fertile forms through doubling of chromosomes, where sterility is due to complete incompatibility between chromosomes of the parents. It is also known to have produced forms resistant to disease, pests, frost, drought conditions, etc. Some species which are not related as polyploids may differ in more complex chromosomal changes. The simplest type of change is the reduplication of one or more chromosomes. These are called modified polyploids or secondary polyploids. Ramanujam and Joshi [1941] have recently summarised the position with regard to the artificial production of polyploids and may be referred to.

By far the easiest and the most successful method for inducing polyploidy consists in the use of the alkaloid, colchicine, in weak concentrations in water to growing parts of plants. Recently, chemicals such as aurantia, diphenylamine, tribromoaniline induced root swellings in barley but were found to be not so powerful as colchicine. Parthasarathy [1942] reports that tubers of *Gloriosa superba* contain the alkaloid colchicine and it may serve as a cheap alternative for inducing polyploidy. It is claimed that even soaking young seedlings in 0.05 to 1.0 per cent colchicine solution produced polyploidy in soyabeans, rice and wheat. Colchicine enters the tissue and inhibits cell divisions while the nucleus and cell volume may increase. Colchicine is found effective on both the premeiotic and meiotic cells. Hedayatullah [1941] reports that colchicine in a weak solution has a stimulating effect on rice. Seeds first soaked in such solution before sowing resulted in plants flowering earlier and yielding more grain than the control.

Haploids and polyploids

Haploids and polyploids in rice are now as commonly met with as in other plant material. The occurrence of triploids and tetraploids in rice was first reported by Nakamori [1932 and 1933] and subsequently a number of spontaneous as well as induced polyploids have come to light. Below is given an account of the several haploid and polyploid plants so far recorded in rice.

Haploids. The first occurrence of a haploid in rice was reported by Morinaga [1932] in a cross between a normal and a dwarf variety. Almost at the same time Ramiah *et al.* [1932] found in their cultures a plant with a dwarf habit, poorly emerging panicle with smaller spikelets and absence of anthesis and completely sterile, which on cytological examination proved to be a haploid. It occurred as a twin in a normal pure line, and it was suggested that it arose perhaps due to the development of one of the reduced cells in the embryosac other than the egg cell. Occasionally the haploid is found to produce a diploid fertile tiller. Pollinated artificially, the haploids set seed though in very low percentages. The ovary is found sometimes to produce seed by parthenocarpy. The meiotic behaviour of the haploid thoroughly studied by Morinaga [*loc. cit.*] *and* Ramiah *et al.* [1934, b] was found to be similar in behaviour to other haploids, in the absence of homologous chromosomes and the random segregation of univalents at the first division (Plate XXXI). Spindle formation was also affected and the cell division was remarkably disturbed. Generally no normal pollen grain was formed or rarely so. A few giant pollen grains observed by Ramiah and others were found to be only monads and were not comparable with those of wheat where multinucleate pollen grains were formed as a result of the coalescence of contiguous pollen mother cells.

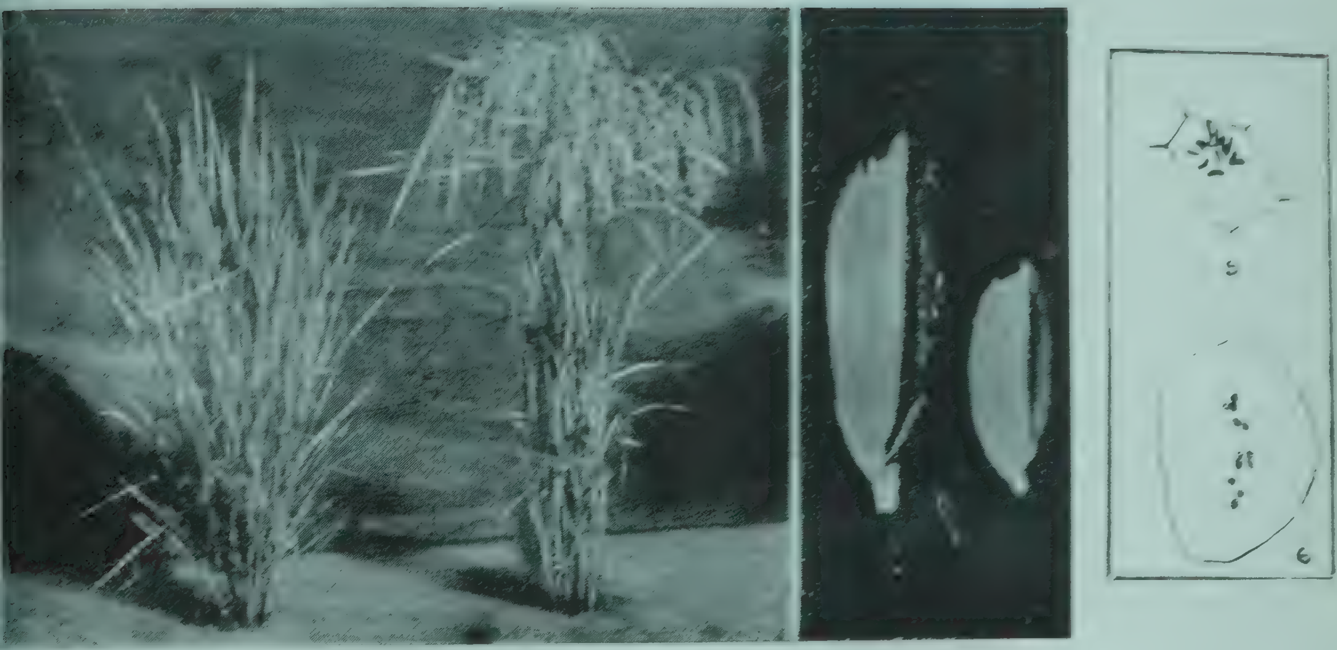
Sethi [1935-37] obtained a haploid plant in an F_3 culture of a cross, but certain tillers of this plant produced panicles with a high percentage of fertile spikelets and these were presumed to be ordinary diploids. Further generations were raised from the seed and also from crosses made between the haploid and the normal diploid. From the segregations obtained, he concludes that haploidy is dominant. Beyond examining the first haploid no further cytological studies have been made. It is very doubtful if the results are as simple as have been represented. The so-called haploids judged from appearance alone might well have been trisomics.

Haploids, as Blakeslee [1939] has pointed out, have a potential value in plant breeding. In the case of interspecific crosses where a large number of Mendelian factors are at work, it is generally very difficult and time-consuming to fix an individual with the desired combination in the homozygous condition. In such a case, if it is possible to produce haploids by parthenogenesis which will contain only one set of chromosomes, the haploid chromosomes could be doubled by colchicine treatment and the resulting plants would be diploids and pure breeding. It would thus appear that the great need in the plant breeding and genetic programme of to-day appears to be a method by which it is possible to halve the chromosome number when desired.

Triploids. Triploids may be broadly classified into two groups (1) the true or autotriploids which have three identical chromosome groups or genomes and (2) the hybrid triploids or allotriploids which have different genomes. The former class of triploids is known to occur in pure lines under common cultivation or in hybrid material. External agencies are also known to cause them. Several clonal species are now identified as true triploids. The allotriploids are known to arise in crosses between diploids and amphidiploids and also in interspecific and intergeneric crosses.

Autotriploids. The first autotriploid mutant in rice was reported by Nakamori [1932] from Japan which was obtained in the eighth generation of an intervarietal cross. Ramiah *et al.* [1933] obtained an autotriploid in the fourth generation of a cross between two varieties of rice. Later, several autotriploids were isolated in commercial varieties. Ichijima [1934] obtained some triploids by X-ray treatment of seeds. Morinaga [1935] isolated as large a number as one hundred and fifty spontaneous triploid mutants in his rice cultures. The origin of the spontaneous triploid is believed to be either due to the union of a haploid gamete with an unreduced diploid gamete or the fertilisation of a normal egg by two male nuclei called 'dispermy'. It is believed by many workers that diploid eggs are more functional than the diploid sperms, and the success of the interspecific crosses where the parent with a larger number of chromosomes is used as the female is cited in support of this belief.

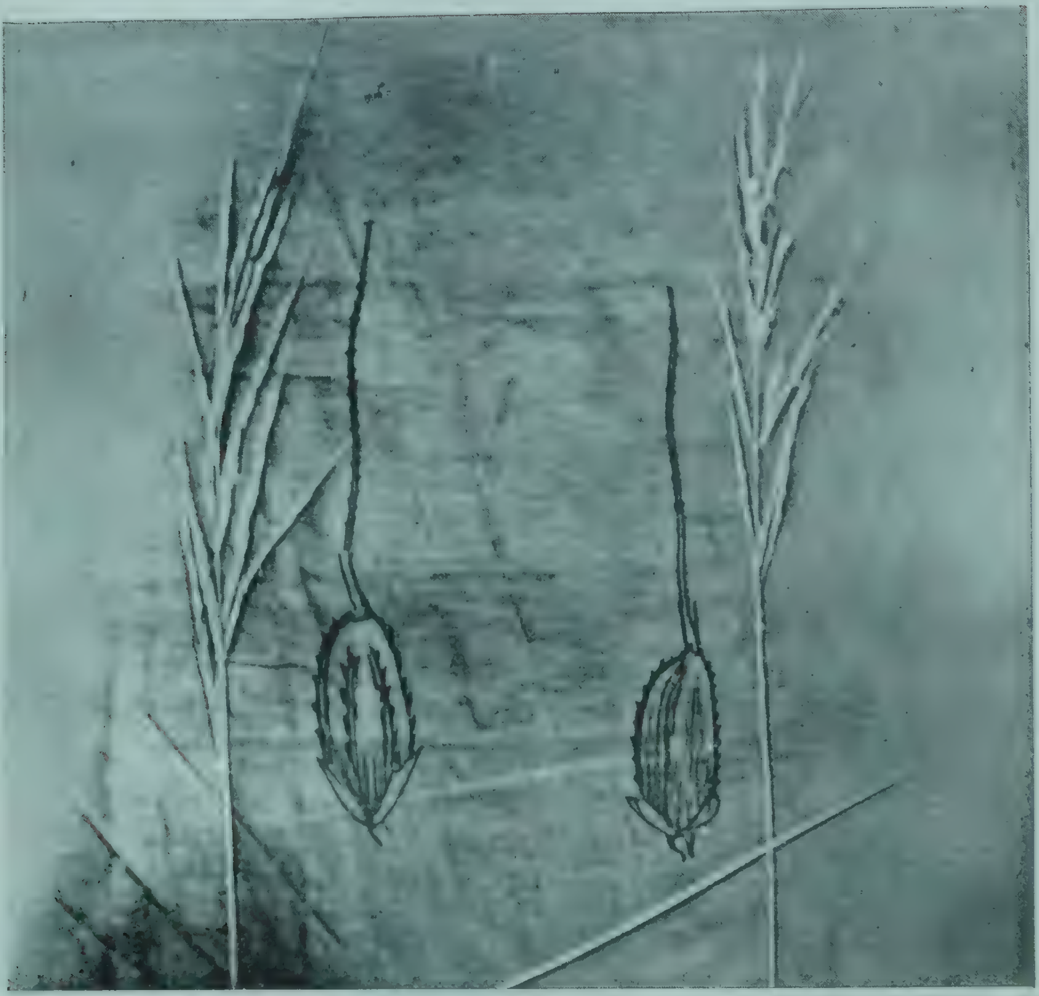
In morphological characters, the autotriploid rice has been found to possess thicker stems, broader leaves and larger spikelets and it does not set seed on selfing. To understand the nature of sterility the meiotic behaviour of these triploids was studied in detail by Morinaga [1935].



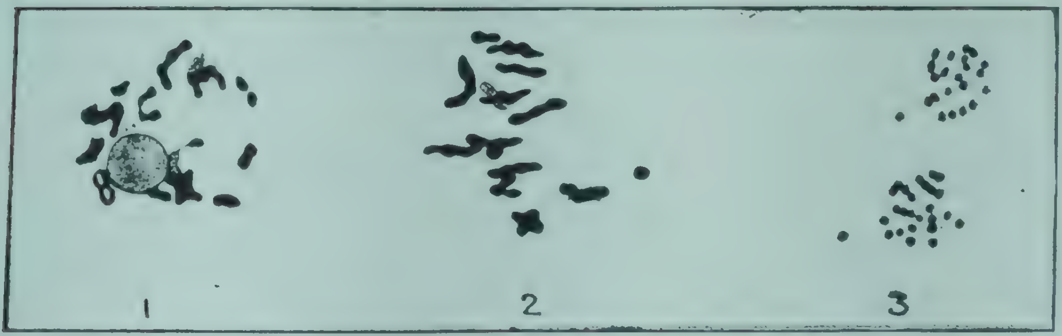
Haploids and diploids

1. Haploid plant
2. Diploid plant
3. Spikelet of the diploid
4. Spikelet of the haploid
5. Metaphase in haploid
6. Pairing in P. M. C.

(After Ramiah and others 1932)



Oryza longistaminata



Tetraploid and diploid in *O. longistaminata.*

1. **Diakinesis in the tetraploid (x 3000).**
2. **First metaphase (x 3000).**
3. Second metaphase showing distribution and secondary association of chromosomes (x 3000).

(After Ramiah and others 1935)

Ramanujam [1937, a] and other workers. At diakinesis and the heterotypic metaphase they observed variable numbers of trivalents, bivalents and univalents. The most common case of association in Ramanujam's material was 10 III + 2 II + 2 I, the trivalents assuming various forms, viz. the rod, the frying pan, the Y, the triple arc, etc. the frying pan type being the most common. In one cell, he noticed an association of six chromosomes, the rest appearing as trivalents, bivalents and univalents. In the heterotypic anaphase, the trivalents and bivalents disjoin into homologues and travel at random forming unequal numbers of chromosomes in the gametes. No case of restitution nucleus formation was noticed by either of the workers. The second division is more regular. The univalents arrange themselves regularly on the metaphase plate, some appearing to be closely arranged to each other like loose bivalents but no trivalent like association was observed. By reduction divisions, four microspores of nearly equal size are produced. Sometimes there is disparity in the division of one daughter cell when a triad would result. These microspores later become vacuolated, shrink in size and finally collapse into empty membranes containing little protoplasmic contents. The percentage of such empty pollen was, however, found to vary with the season of flowering. It has been found that failure of homologous chromosomes to pair was governed by genetic factors and it remains to be established if such agencies may also be at work for the failure of separation of the trivalent associations noted by Ramanujam, who obtained a few fertile seed when the sterile triploid was intercultured with normal diploid plants giving rise to polysomics which are described later.

Allotriploids. Allotriploids, as has already been pointed out, arise in interspecific crosses [Nandi, 1936-38, Ramanujam, 1937]. Those reported by Nandi in rice arose in a cross between *O. minuta* and *O. sativa.* The F_1 hybrid was triploid with 36 somatic chromosomes which arranged themselves into 12 bivalents and 12 univalents. Generally no trivalents were found showing that the triploid hybrid contains one dissimilar set of chromosomes. There were a number of irregularities in the anaphase and second division, the pollen grains were empty and their variation was also well marked. At Coimbatore, an infertile F_1 between *O. sativa* and *O. officinalis* when intercultured with normal diploid plants, set ten seeds and these gave rise to triploids.

Tetraploids. As in the case of triploids, tetraploids are also of two kinds, (1) the true or autotetraploid and (2) allotetraploids (amphidiploids or double diploids). In the former, there is a reduplication of similar sets of chromosomes from the same species and the latter results from a reduplication of the different sets of chromosomes derived from the hybridisation of different species.

A tetraploid (with 4n somatic chromosomes) is believed generally to arise from the union of one unreduced egg (2n) with an unreduced (2n) sperm brought in by the pollen. In the case of rice it has been shown by Nandi [1936, b] that diploid gametes are of frequent occurrence. Different methods which result in the formation of unreduced gametes have been observed by him as well as other workers both in cultivated and wild rices. Tetraploids have also been produced experimentally by raising the temperature of the surrounding atmosphere when the rice plant is in flower [Nandi, 1936,

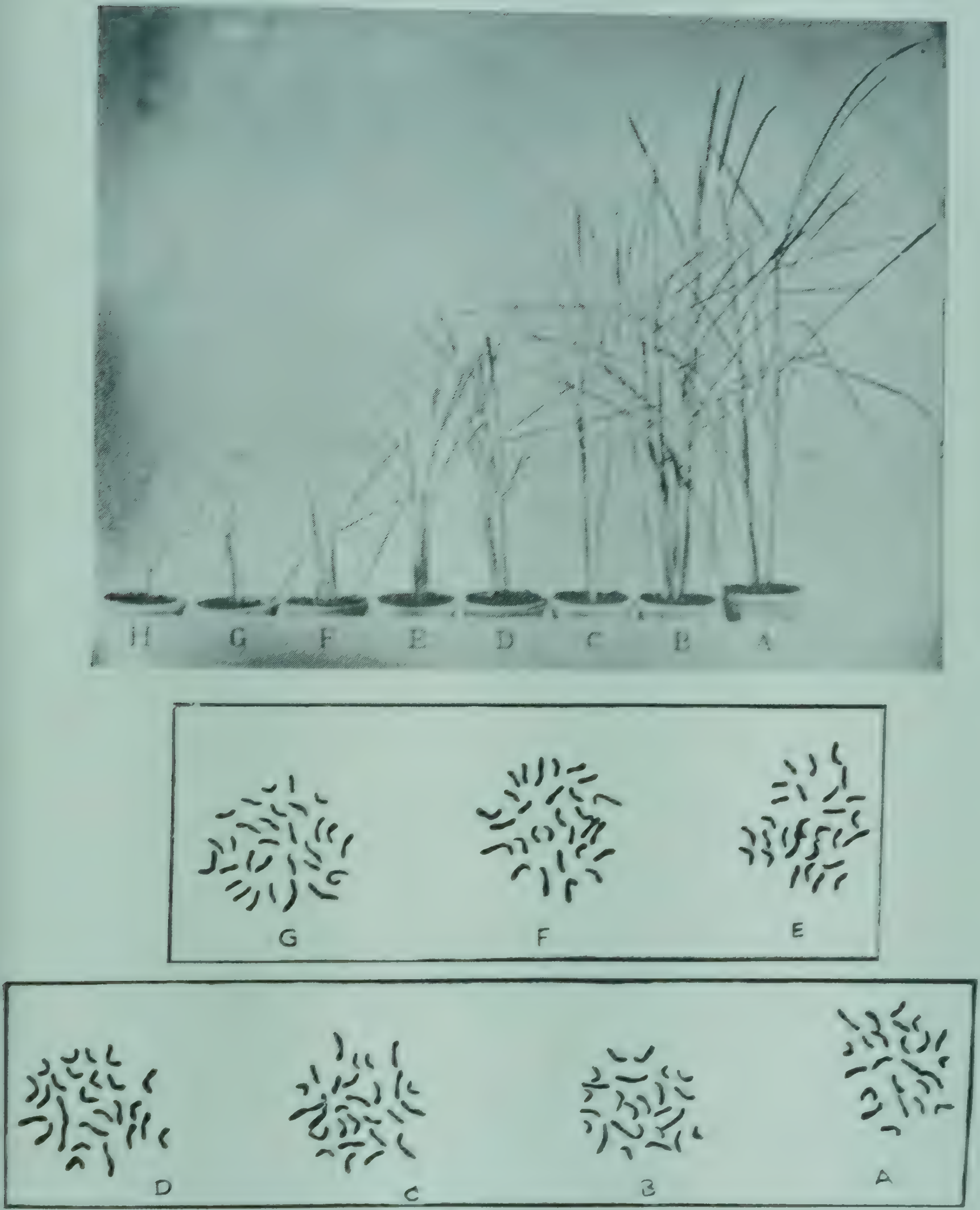
d. Most of the spontaneous autotetraploids in rice seem to owe their origin to this method.

Autotetraploids. An autotetraploid rice plant occurring spontaneously in the F_2 progeny of an intervarietal cross was first reported by Nakamori [1934] from Japan. Later a tetraploid plant in the wild species *O. longistaminata* (Plate XXXII) was described and studied by Ramiah *et al.* [1935]. In highly sterile races, Morinaga and Fukushima [1936] discovered autotetraploids on six occasions with long ears but greatly reduced fertility, and other organs slightly increased. Gigantism in floral parts and specially in the pollen grain is the chief characteristic by which these may be distinguished. These are generally very much poor in fertility. Cytological behaviour of these mutants show a characteristic quadrivalent formation of varying shapes (rings, rods, Ss), of varying sizes, although trivalents and univalents are also noted occasionally. The normal number of quadrivalents noted was ten or eleven though occasionally cells with as few as seven were also found. Several irregularities like unequal disjunction, the presence of lagging and straying chromosomes both in the first and second divisions are noticed, and this would account for the sterility in tetraploid rice which is however not so common in tetraploids of other crop plants. Srinivasan [1939] however observed an autotetraploid mutant breeding pure which was found to be due to the regular formation of diploid gametes during meiosis, though the maximum quadrivalent formation was up to nine.

By cytological studies of the diploid and haploids it has been established by Nandi, Ramanujam and others that rice is a secondary balanced allopolyploid with a basic number of five chromosomes and this has been already referred to. It has also been suggested that the wild rice species of *O. minuta* has arisen as a hybrid between *O. sativa* and *O. officinalis* followed by chromosome doubling. The synthetic production of *O. minuta* (now that its chromosome complement is definitely known) by crossing these two species which contribute to its genomes followed by chromosome doubling should only be a matter of time. The importance of allopolyploidy in evolution lies in the fact that it induces far reaching effects by changing sterile species into fertile forms, an annual into a perennial, etc. Autopolyploidy on the other hand has given rise to a diversity of opinion with regard to its part in evolution. While some believe that autopolyploidy has played a part in evolution, others think that new polyploid species cannot possibly arise by multiplication of the same genome alone. Autopolyploids normally do not show great differences in morphological characters from the diploids except for certain size variations; they are slower in development, later in blooming and do not cross with diploids [Ramanujam and Joshi, *loc. cit.*].

Polysomics

Polysomics are plants with one, two, three or more extra chromosomes besides the usual diploid complement, and they are known to arise from triploids as a result of meiotic irregularities. These polysomics have been obtained in a triploid progeny of rice [Ramanujam 1937 a and Parthasarathy 1938a]. The triploid had sterile pollen but when intercultured with normal diploid plants gave rise to polysomic progeny showing that the extra chromosomes were contributed by the triploid. Ramanujam [*loc. cit.*] had studied polysomics in rice in which the somatic number of chromosomes varied from 25 to 30. (Plate XXXIII). It would be expected that in the distribution of chromosomes to daughter cells in the triploid,



Triploid offspring with different chromosome numbers (Polysomics)

A. plant with 2 n = 24.
B. plant with 2 n = 25.
C. „ 2 n = 26.
D. „ 2 n = 27.
E. „ 2 n = 28.
F. „ 2 n = 29.
G. „ 2 n = 30.
H. plant drying very early.

(After Ramanujam 1937 a).

there should be the ordinary separation of the chromosomes of the two genomes plus the random segregation of the odd genome, so that gametes are produced with an approximately binomial frequency distribution of chromosomes ranging from the haploid to the diploid number. Although this should generally be the case in all triploids where the meiosis is regular without much elimination of chromosomes due to lagging, in certain cases as in rice studied by Ramanujam, this distribution is however upset. In the rice triploid, it has been found that polysomics with chromosome numbers higher than 30 were never realised and even in the lower ones the proportion of plants obtained in each class relative to expectation diminished from 24 to 30 chromosomes. Corresponding decrease in vigour of the plants was also noticed. Most of these polysomics which were grown and studied in the green house at the Courtald Genetical Laboratory, Regents Park, London, did not flower at all probably due to unfavourable weather conditions. A preliminary study of the meiotic behaviour of the trisomic (2n = 25), tetrasomic (2n = 26) and pentasomic (2n = 27) was made by Ramanujam, and his publications may be referred to for details.

CHAPTER XIX

QUALITY IN RICE

IMPROVEMENT in rice culture has hitherto been carried along the lines of increasing the yield and improving other hereditary characters that enable the cultivation of a successful crop. Although for a long time to come, introduction of new and high yielding strains should be the primary concern of the rice breeder, particularly because of the fact that the acre yields in India are still comparatively poorer than in several other countries, and that only a fraction of the total rice area is yet covered by the improved types evolved by the plant breeders, yet, there is no doubt that sufficient attention has not been given towards improving quality in rice. It may be useful to remember in this connection that the maximum improvement in acre yields that may reasonably be expected out of the efforts of the plant breeder cannot be more than 15 to 20 per cent, and further increases can only be achieved by changing the cultural and manurial practices. These changes in the cultural and manurial treatments if, in addition to their improving the acre yields, can also improve the quality of the produce, as they appear to do, may go a long way in improving the standard of health of the average rice eater.

Unfortunately, the problem is beset with many difficulties. Quality itself, as popularly understood, is very difficult to define precisely. In some cases, it is made up of certain physical characters of the grain, such as size, shape, colour and behaviour on milling or on cooking; in others it depends largely on properties such as taste and flavour which are somewhat vague entities but are yet quite real. Quality often also includes a recognition of the general nutritive value, digestibility, energy value, presence of certain essential food constituents and such like. Thus the number of factors which make up quality and the complexity of their interrelationships render a scientific investigation of quality very laborious and sometimes inconclusive. This is specially so in a crop like rice, where the conception of quality varies frequently with different interests. Thus the producer's idea of quality is dependent upon the net profit he gets from his produce and ignores all other characters. The trader bases his preference on the yield of head rice on shelling, milling quality, storage properties, etc. The consumer's demand for quality is chiefly determined by external appearance or some other artificial distinctions. Finally, the scientist's interpretation of quality in rice lies solely in its nutritive value which, in turn, is dependent on its chemical composition.

It would seem highly desirable to reconcile some at least of these conflicting ideas and breed for better quality. Here lies a fruitful line for cooperative research on the part of the breeder and the chemist. As most of the rice produced is required for consumption, we are essentially concerned with quality from the point of the consumer and his health. A consideration of the nutritive properties of rice in its varied aspects is of special importance in a country like India where, unfortunately, the majority of people have not yet learnt to take a serious view of the nutritive value of the foods they consume and their balance in the daily diet. During recent years, however, there have happily been some encouraging signs of an awakening in the nutrition-consciousness of the people, especially of the upper and middle classes.

Extensive biochemical investigations of quality in rice have been carried out by Dr. A. Srinivasan and his associates at the Indian Institute of Science, Bangalore, in close cooperation with the Paddy Section of the Agricultural Research Institute, Coimbatore. These researches which were sponsored by the Indian Council of Agricultural Research together with later work from Dacca, Coonoor and Coimbatore have been particularly helpful in assessing the scientific basis for several popular beliefs, and in offering possibilities for improvement in the present status of the rice diet. In the following paragraphs the different aspects of quality are briefly discussed and indications given as to how changes in quality can be brought about by changes in local practices either in rice culture or in processing the grain for food.

1. AGRONOMIC FACTORS AFFECTING QUALITY

The most important of the agronomic characters of rice varieties is the yield. Some of the other features for which particular varieties find favour in the choice of the agriculturists are resistance to diseases, pests and adverse weather conditions, decreased shedding and increased ease of harvesting and threshing. While rice is essentially a wet crop, requiring prolonged swamp conditions during the major part of its period of growth, it is also highly adaptable to varying amounts of water. In certain areas which are subject to fluctuations in rainfall and field levels, rice is grown as an intermittant dry and wet crop. Irrigated rice is, however, more productive than dry rice although the latter is believed to be more nutritious.

Length of growing season is another important character distinguishing rice varieties. This varies from a scant three months to a full eight months. The cultivator chooses the short period crop in anticipation of either irrigation facilities for two or more crops in a season or unfavourable climatic conditions which might destroy a long duration crop. It is generally held that short duration varieties are poorer in quality than long duration ones because, they are assumed to remove less of plant food from the soil. Thus short duration *kuruvai* or *kar* varieties of South India and *aus* rice of Bengal are not valued as much as the long duration *samba* and *aman* rices of the respective regions. The so-called inferior quality of the short duration rices may be partly accounted for by the fact that the climatic conditions prevailing at the time of harvest preclude the possibility of obtaining a uniformly mature product; moreover, the harvest of these varieties comes in at a time when there is general scarcity of grain and people are obliged to use it for food immediately after harvest.

2. QUALITY IN RELATION TO MARKET VALUE

(a) *General.* Chief consideration is the ratio of the yield of rice to whole grain. This varies between 70 and 85 per cent by weight and usually coarse and large grained varieties have a smaller proportion of hull than the small grains. This is, however, different from the position in the European markets where large bold grains like *Blue rose* and *Carolina*. which would be considered highly coarse in the Indian market. obtain a premium.

Size of grain is another familiar character determining the market value of rice varieties. The classification adopted is more or less coarse, medium and fine. The fine varieties possessing a fairly high length to breadth ratio and a small size are liked by the rich and well-to-do, and fetch good prices. But the thick, squat, large and bold grained varieties which are generally consumed by the poorer classes of people fetch low prices.

Another important quality finds expression in the appearance and texture of the grain. Some varieties are hard and flinty while others are soft and mealy. The latter are usually characterised by a white starchy abdomen and they easily break while milling. The harder and vitreous grains suffer less by breakage during milling and hence obtain a better price in the market. Glutinous rice has a uniformly chalky appearance and the grains are fairly hard. It contains a high percentage of soluble starch and dextrins. Very little is known regarding the nature of the relationship between hard, soft and glutinous varieties in regard to their make up of starch and the nature of the other constituents which determine the hardness or otherwise of the kernel.

One other general classification is into white and coloured rices; the coloured grain includes light red, red, and purple of various shades. The colour is always superficial. The preference, however, is everywhere for white rice; there is no market for red or coloured rice as such and their presence in white rice depreciates the price greatly. In a few places, however, recognised coloured rices are deliberately grown because of distinctive high yield or the belief that they are especially nutritious as in Malabar (in Madras) and Ceylon.

(b) *Keeping quality of rice.* Exported rice and a very large part of the grain used for home consumption are entirely machine-milled. The unpolished rice does not keep well in a tropical climate, and rapidly loses its flavour. Again it becomes infested with insects which destroy the outer mealy layer of the grain; the rice soon becomes mouldy and off flavours develop.

The deteriorative changes of unpolished rice on storage result from the presence in the outer layers of a resistant fat splitting enzyme and its action in presence of air and moisture on the bran oil which is easily decomposed, resulting in a mixture of free fatty acids. These, in turn, undergo oxidation and the fats acquire an unpleasant odour and taste and become rancid [Srinivasan, 1937]. Desiccation combined with air-tight packing can be successfully employed for the preservation of unpolished rice but there is great need for evolving other and more practicable methods for improving the keeping quality of shelled, unpolished rice.

(c) *Polishing of rice.* To produce a rice which can be handled without commercial hazard, the rice kernel is passed through a combined scraping and polishing process. This removes the outer coating of the kernel known as the 'silver skin' and the germ or embryo. Polished rice, on account of its better keeping quality, taste and clean white appearance, sells more readily than unpolished rice. In addition, the bran fetches a price of its own.

(d) *Parboiling of rice.* Another unique feature of the rice problem relates to the process of parboiling. The yield of head rice comprising the whole kernels is an important item both for the grower and the miller. The factors which contribute to high milling quality in rice are yet ill-defined. The soft and mealy types of rice and the coarse-grained varieties which are also usually short duration crops, break enormously during milling.

From very early times it has been recognised that parboiling improves the milling quality of rice. This process not only loosens the husk but it also toughens the grain thus permitting of more severe milling [Subrahmanyan *et al.* 1938]. Parboiling by different treatments to varying extents affects the milling quality of rice also to different degrees as can be seen from the figures given in Table XXI.

TABLE XXI

Percentage loss of nitrogen and phosphorus on polishing

(Variety Adt. 11)

Degree of polishing per cent	Raw rice		Parboiled rice	
	Total N lost per cent	Total P lost per cent	Total N lost per cent	Total P lost per cent
2·0	1·98	8·12	2·37	7·51
3·0	3·03	12·92	3·30	11·67
5·0	5·33	21·71	4·92	19·50
7·0	7·57	30·52	6·92	28·08
9·0	9·73	39·51	9·24	37·74
11·0	11·81	47·57	11·65	48·47
13·0	14·13	54·37	14·17	60·13
15·0	16·16	60·62	16·93	70·50
18·0	19·30	69·41	20·93	85·50

Parboiled rice is also reputed for its better keeping quality. This may be due to the action of heat on the fat splitting enzyme and, or to a change in the nature and make up of the rice oil. When cooked, it keeps well for considerable lengths of time either by itself or soaked under water. Besides, it is claimed to possess greater sustaining power.

Irrespective of the variety chosen, parboiled rice is generally darker in colour than the corresponding raw rice. The colour is partly derived from the husk but is mainly due to the partial dextrinization of the rice starch, Subrahmanyan *et al.* [*loc. cit.*]. It is possible under certain controlled conditions to produce parboiled rice with minimum discolouration. Commercial specimens of parboiled rice often have an objectionable flavour which is due essentially to bad water being used for soaking and to undesirable fermentation changes. Ideally prepared, parboiled rice has a pleasing flavour

(*e*) *Storage changes in rice.* It is a matter of common experience that rice prepared out of freshly harvested grain is unfit for consumption and sells at a discount in the market. New rice cooks to a shapeless, pasty condition swelling scarcely to twice the volume of the original uncooked product, while the well-stored grain cooks to a fine, fluffy consistency, the volume of the cooked product being three to four times that of the uncooked rice. Several theories have been advanced to explain this peculiar difference in cooking quality between unstored and well-stored rices. The real explanation would appear to lie in the presence in the outer layers of freshly harvested rice, of an active amylase which during storage becomes dormant and inactive [Srinivasan, 1939, a]. Parboiling is one of the methods by which the cooking quality of unstored rice can be improved. Storage changes are also hastened when the grain is kept underground or in airtight containers. Refrigeration retards improvement on storage [Anonymous; 1938].

3. CHEMICAL COMPOSITION OF RICE VARIETIES

(a) *Coloured and coarse rices* versus *white and fine rices.* The chemical composition of rice has been determined by a number of workers, and despite the large number of rice varieties, the average values for the different constituents as reported by several investigators fall within a narrow range. Between individual varieties, however, the composition varies rather widely. Of especial significance has been the observation that coloured and coarse grained rices generally contain larger amounts of proteins and minerals particularly calcium, phosphorous and iron, than the so-called superior fine varieties [Srinivasan and Sadasivam, 1938]. The coarse varieties have also to be polished to a higher degree than the fine ones before a white grain results. Histological examination [Ramiah, *et al.*, 1936] has also shown that thev possess thicker bran layers than the fine varieies as shown in Table XXII.

TABLE XXII

Thickness of bran layers in rice

Variety	Grain size (coarse, fine, etc.)	Rice colour	Thickness of bran layer in microns (Pericarp aleurons)	
			Dorsal side	Ventral side
Black puttu	Coarse	Purple	62·3	40·5
T. 303	Do.	White	53·3	37·4
T. 326	Do.	Do.	54·1	32·8
T. 88	Do.	Gr. Brown	48·8	32·1
T. 219	Do.	White	50·1	36·6
Co. 4	Do.	Do.	48·1	28·5
T. 29	Do.	Red	52·8	39·3
T. 248	Do.	Do.	44·1	38·3
T. 375	Do.	Do.	41·0	31·3
T. 73	Medium	Do.	54·8	33·8
T. 132	Do.	Brown	56·6	39·1
Co. 6	Do.	White	43·8	28·8
Co. 5	Do.	Do.	44·5	30·3
Co. 7	Do.	Do.	41·8	31·6
Co. 2	Do.	Do.	47·8	28·8
T. 218 (Adt. 4)	Do.	Do.	36·8	21·3
T. 217 (Adt. 3)	Do.	Do.	36·0	22·0
Co. 3	Do.	Do.	34·3	22·0
Co. 1	Medium fine	Do.	42·3	25·8
T. 2	Fine	Do.	42·6	25·6
T. 124	Do.	Do.	47·1	27·3
T. 109	Do.	Do.	37·8	24·8
Geb. 24	Do.	Do.	35·3	26·1

Since short duration rices are generally coarse grained it would follow that there is also no scientific basis for the popular belief that they are inferior to the long duration crops as can be seen from the composition of rices given in Table XXIII.

TABLE XXIII

Composition of rice samples (oven dry basis)

Variety	Duration (days)	Protein per cent	Total mineral per cent	P_2O_5 per cent	Cao per cent
Adt. 6 ..	180	8·67	1·85	1·28	0·10
Adt. 3 ..	100	10·47	1·62	0·82	0·12
Co. 9	100	9·59	1·76	0·73	0·10
Co. 10 ..	120	7·61	1·65	0·79	0·06
Adt. 7 ..	180	7·26	1·70	0·56	0·13
Geb. 24 ..	160	6·97	1·66	0·54	0·07
Adt. 11 ..	170	6·59	1·46	0·70	0·09

(b) *Effect of manuring.* Recent research in malting and bread making have shown that low nitrogen barley and high nitrogen wheat are respectively best suited for these purposes. Following on this, it has been shown that the nitrogen content of wheat and barley varieties can, within limits, be altered by suitable systems of manuring. It is similarly possible to improve the quality of rice by increasing the protein and mineral contents of the grain by judicious control of fertiliser applications. Thus in a particular experiment carried out at Pattambi, Madras 1935, it was found that application of fertilisers in instalments during the life of the crop and up to the flowering period was definitely favourable, the protein content being increased in one instance to the extent of 20 per cent. Histological examination of rice grown under different manurial conditions has also revealed that manuring results in an increase in the thickness of the bran layers.

(c) *Effect of irrigation.* While dry rice is less productive than irrigated swamp grown rice, it is considered to be more nutritious. It has been shown, however, from a study of three upland rices, *modan*, that when the same variety is grown under dry as well as wet conditions the latter contains more proteins and minerals than the former [Srinivasan and Sadasivan, 1942]. There is however, a reverse relationship in regard to the fat contents of the different samples.

(d) *Effect of polishing and parboiling.* It is well known that in the process of polishing the rice, the grain loses all the outer envelope or bran and the germ. These together constitute really one-eighth of the whole grain but contain more than half the mineral matter, a fourth of the proteins and practically all the fats and vitamins. Numerous workers have drawn attention to the high concentration of essential nutrients in the peripheral layers of the grain and to the waste associated with polishing. It is, however, recognised that parboiled rice even after polishing possesses a comparatively higher nutritive value than raw rice. Recent researches on the changes in the chemical composition of rice varieties, both raw and parboiled, as a result of polishing to different degrees have shown that polishing in the earlier stages is not accompanied by as much loss of proteins and minerals with the parboiled specimens as with the raw rices, Subrahmanyan *et al.*, [*loc. cit.*]. With increase in the degree of polishing the extent of losses is reversed. These results are understood, when it is realised that during parboiling the inner endosperm or starch tries to swell, but since there is the outer bran and the inelastic husk, the result is only a kind of imbedding of the bran layer inside the endosperm. A diffusion of vitamin B_1 from the integuments inside the grain has also been reported in this connection [Aykroyd, 1932].

The basis for the general superior nutritive value of parboiled rice even on polishing would, however, appear to lie in the facts that (i) parboiled rice of commerce is often prepared from coarse varieties which do not mill well when raw; (ii) it is not polished to a high degree of whiteness, because parboiling produces translucency and creamy colour in the grain, and because it is not possible to improve the colour by polishing alone beyond a degree and (iii) parboiled rice is generally under-milled also because the outer coat gets toughened as a result of parboiling.

(e) *Mode of preparation of rice.* Repeated attention has been drawn to the wasteful processes of washing rice before cooking and of throwing away the water in which the grain is boiled during cooking. Happily there has been some improvement in regard to the latter, for in most well regulated households only enough water is used to enable the rice to cook to its proper consistency. The losses on washing are less well recognised and are perhaps even more wasteful. Washing is necessitated on account of certain extraneous articles used for blazing and finishing rice.

4. NUTRITIVE QUALITIES IN RICE

(a) *The nutritive constituents in rice.* There is ample experimental evidence to show that rice protein, small as it is in quantity, is nutritively superior to that of wheat. It is richer in regard to the essential aminoacids and promotes better growth than wheat protein. In its general aminoacid make-up, it has been compared to the proteins of meat, milk and soya bean [MacCollum and Simmonds, 1917].

Some varieties, especially the coarse and coloured ones, are rich in phosphorous which is necessary for the building of the bone; others are comparatively poor. A large part of the phosphorous is present in organic combination as phytin which is said to be poorly available to the animal organism. Recent work at Bangalore, which has since been confirmed from elsewhere, has shown that the phosphorous in rice is not unavailable [Srinivasan, 1936, b].

The commoner varieties of rice are deficient in lime. The ratio of phosphoric acid to lime is of the order of 10 to 1 whereas it ought to be somewhere about one to one or one to two. Hence supplements of lime in the form of milk, vegetables and other food articles will favourably influence the assimilation of the phosphorous compounds in rice.

The iron content of rice is rather small, yet, as a source of this valuable constituent its importance cannot be ignored in view of the fact that rice occupies a very large proportion in a rice dietary. It is noteworthy that many coloured varieties of rice contain nearly two to three times the amount of iron present in the commoner white ones.

Rice oil is considered to be nutritious but the small amount present in the whole grain assumes importance as the carrier of the important vitamin E. Rice is not an important source of vitamin A but it certainly contains some. Rice has for long been recognised as amongst the richest sources of vitamin B .

(b) *Nutritive value of rice varieties*. Extensive growth experiments on young albino rats and pigeons fed with different varieties of rice have shown that given adequate supplies of the antineuritic and other vitamins the differences in growth rates are essentially related to their compositions [Srinivasan, 1942]. The average weekly growth rate Y was found to be governed by the multiple regression equation :

$$Y = 0.42\ x_1 + 7.34\ x_2 + 3.43\ x_3$$

where x_1 is the protein content. x_2 is phosphorous compounds and x_3 minerals excluding phosphates. The coloured and coarse rices promote better growth in young rats than fine rices. Similarly irrigated transplanted rice is better than dry broadcast rice, irrigated broadcast rice being intermediate in nutritive value [Srinivasan and Sadasivan, 1942]. This latter finding contradicts McCarrison's work [1928], where the test samples of rice constituted only a fraction of otherwise perfect diet.

An interesting observation that has emerged out of this growth studies relates to the fact that young rats when fed on diet with rice as the sole source of proteins. do not grow in weight beyond 100 gm. total body weight. This would suggest. that in spite of the rice protein being of a superior quality. the level of protein supply as provided by this cereal is inadequate over prolonged periods. This in itself is not a serious thing. For, in ordinary practice. rice forms only part of a good mixed diet. Coonoor work [Aykroyd *et al.*, 1940], on feeding groups of young rats with a basal rice diet together with supplements like casein. calcium lactate and skimmed milk have shown, that casein produced a definite improvement in the growth rate, and that while calcium lactate was better in this respect, skimmed milk gave the most striking improvement as shown below. Thus a supplement of calcium and protein is better than either of these constituents given singly.

Effect of supplementing a poor rice diet

Particulars	Amount of supplement given* (oz.)	Average weekly increase of weight for 10 weeks (gm. per rat)
Poor rice diet alone	..	2·9
Supplemented by :		
Casein	1·50	4·1
Calcium lactate	0·25	7·0
Skimmed milk powder	1·50	9·0

---

*The amounts of supplements added, like the basal diet itself, were conceived in terms of human daily intake.

Since the nutritive values of rice varieties are mainly determined by their composition, it would follow that there is great need for improving quality in rice along the lines of enriching its composition by breeding, if possible, and by manurial and other cultural operations.

(c) *Digestibility of unpolished rice.* It is generally held that unpolished rice is more difficult to digest than polished rice. *In vitro* digestibility trials [Srinivasan and Venkatagiri, 1939] have shown that the difference in digestibility between unpolished and polished rices is too small to be of any significance in practice. Unpolished rice is richer than polished rice and bulk for bulk it contains more solid matter since it does not swell to the same extent on cooking. Hence it has to be taken in smaller quantities.

(d) *Ill effects of fresh rice.* It is largely borne out by experience that consumption of cooked rice, from freshly harvested grain, causes digestive disturbances. Recent evidence would suggest that the decreased capacity for swelling on cooking of new rice is essentially responsible for its lower digestibility [Srinivasan, 1939, a]. It offers a smaller reactive surface for the digestive ferments. Even in experiments where the action of certain moulds on rice cooked to different degrees was studied, it has been observed that when the individual grains stand apart the mould threads penetrate through them easily and convert them into sugars and other products, whereas when rice is otherwise rendered squashy, the moulds penetrate only partially leaving the hard central portions unattacked. Another psychic reason for the digestive disorders accompanying the consumption of cooked new rice may be that it has a smaller filling power, poorer than an equal quantity of cooked stored rice, and hence there is a probable tendency to overeat.

5. GENERAL CONCLUSIONS

(a) *Factors tending to lower the food value of rice.* A unique circumstance that distinguishes rice in its study as an article of food from all other cereals is that it is the only grain which is consumed predominantly as cooked whole grains. Naturally the preference has everywhere been for external characteristics, chiefly appearance. A direct outcome of this has been to relegate into the background coloured and coarse varieties. The plant breeder has only been catering hitherto to the popular demand for the fine and high yielding varieties. Nutritive value has yet no place in his scheme. If, therefore, there is an awakening to the situation and the public demand nutritively superior varieties, there is no doubt that the position can soon be reversed.

In addition to the prevailing taste for fine, white and small or long grained varieties, which has resulted in the choice of 'wrong' varieties and their multiplication, the poor quality of rice as ordinarily consumed, is also traceable to (1) the process of polishing which removes the major part of the protein and phosphorous compounds as well as the essential vitamin, (2) the practice of thorough washing before cooking which removes a further part of the residual bran, and (3) the present method of cooking involving loss of gruel containing essential food ingredients.

(b) *Rice* versus *wheat.* It is interesting to note that if wheat and rice are compared on the basis of identical dietary proportions of the whole unpolished grains, rice will approach wheat in nutritive value. Although wheat is richer in proteins and minerals, rice protein is more assimilable. Also, some varieties of rice compare favourably with wheat in regard to composition and, as already pointed out, it is possible to enhance to some extent the nutritive value of rice by cultural methods. The superiority of wheat protein over that of rice is mainly physical in that it lends itself to the preparation of an attractive and palatable bread. As a staple food, rice has calorific value higher than wheat although when ready for consumption it is bulkier and contains more water than a quantity of wheat of equal calorific value.

(c) *Why polishea rice is favoured.* In spite of the fact that the food value of rice loses by polishing, polished rice is nearly everywhere preferred. The reasons are, as stated above that polished rice has a pleasing appearance and texture; it cooks more easily and to a better consistency than the unpolished grain and in the raw condition, it keeps far better and can be stored for long periods or transported over long distances without appreciable deterioration. The chief obstacle against the widespread adoption of shelled unpolished rice, in place of the machine milled product, lies in its poor keeping quality. For this reason it is not a practical proposition to ask people to go back to unmilled rice but even a lower degree of milling would do a great deal of good. It should be possible by proper control measures and propaganda to check the production of highly milled rice and to encourage undermilling. The change over from machine milling to hand pounding might involve an extra cost which, however, is out of all proportion to the gains that result firstly from the greater output of rice to grain and secondly from the better food value of the produce.

6. PRESENT POSITION

It is, however, essential not to forget that rice like all other cereals is a poor article of food even in the unmilled condition, unless it is correctly supplemented by other constituents lacking in it. Considering the great necessity to improve the existing status of rice diet in the country, improvements can be attempted under two directions, (i) encouragement of undermilled rice and (ii) more extensive use of parboiled rice. Nearly three-fourths of total rice grown and consumed in the country is husked by hand and only one-fourth is dealt with by the mills. This is a welcome position from the nutrition point of view as the hand pounded rice is never well polished. Rice pounding as a cottage industry, whether for the preparation of raw or parboiled rice, continues to hold ground in several parts of the country, Bengal, Orissa and small areas of Madras.

(a) *Under milling.* Primarily to obtain a greater outturn of rice to grain, polishing of rice to a high degree in the mills has been prohibited by Mill Licensing Orders of Governments. Though such administrative action was not appreciated by rice consumers in the beginning, they are gradually getting used to undermilled rice. It has to be pointed out in this connection that it is difficult to enforce the regulations strictly. There is no quantitative criterion to determine the degree of polishing a sample has undergone in the mills. The degree is determined empirically based mainly on the colour of the milled sample. When it is remembered that the mills have to deal with mixed grains varying in size and shape, colour and thickness of the bran layer, the finished product can never be uniform in nutritive value. Moreover, most of the existing mills in the country are old, worn out and inefficient. It will never be possible to turn out a uniformly polished sample of rice. The processing in such mills also leads to considerable losses of human food because of the high percentage of 'breakages'. While rapid progress and improvements in the machinery are known to have taken place practically in every other industry, rice milling industry in India has more or less remained stationary for the last several years. While the bran layer of the rice is the seat of the essential nutrients such as ash, phosphorous, vitamins, fat, etc. recent work in the United Kingdom has brought to light that the vitamins, particularly thiamine, is most concentrated in scutellum. This is the layer of cells contiguous to the bran layer next to the embryo and it is stated that during the milling, if so designed as not to remove this layer, a fairly high thiamine content can be retained in the milled sample. This will, however, be practically impossible to achieve with the existing mills.

(b) *Extensive use of parboiled rice.* With regard to more extensive use of parboiled rice we have again to turn our attention to the mills which are concerned in preparing this product. Fortunately, most of the parboiled rice consumed in the country is obtained by handpounding. It is the product that is turned out in the mills that is not satisfactory. The rice has a creamy to dark brown colour and even this is not uniform. There also exist flavour variations on cooking which are sometimes unpleasant. These defects prevent the acceptability of parboiled rice as food. Biochemical research in the country has shown that these defects are due to faulty technique adopted by the mills, and if the technique could be standardised, a more acceptable product can be turned out. It is also stated that an essential equipment in the preparation of parboiled rice of good quality is an artificial drier which unfortunately none of the mills in India has. It is therefore doubtful if the standardisation of the technique alone will improve the quality of parboiled rice. Improvements in the technique should be such as to get a product which is acceptable even to people who are now accustomed to using raw rice. While there has been no change in the methods adopted by the mills in India, there have been several attempts in recent years to modernize and improve the traditional parboiling process outside India, particularly in the United Kingdom, Italy and the United States of America. The most notable among these is the 'Rice Conversion Process' developed by Hausen Laub. The claims made for converted rice, namely, (a) better nutritional value, (b) resistance to infestation, (c) higher milling yield, (d) long storage life comparable to ordinary polished rice and (e) better appearance when cooked have all been substantiated. The improvements here can be considered to have reached a level that will make the rice acceptable to all people. Proposals to set up a model conversion plant in India have had to be given up because of its high cost and its too large a size. There has been a still another development, namely, the 'Malek Process' which for practical purposes is the same as the 'Conversion Process' except in minor details. There is, however, an important advantage in that plants very much smaller than the conversion plant can be obtained. While it was found that the converted rice took a longer time for cooking than raw or parboiled rice it is claimed for the malekised rice that it takes much less time to cook.

(c) *Artificial enrichment*. There is also another point that has received considerable attention in America in recent years, namely, the artificial enrichment of rice. The justification for this has been that even the natural nutrient content of the unmilled rice is limited and varies according to soil, climate, variety, manurial practices, etc. under which the crop is grown. Hence it is not possible to get a rice ' nutritionally well-rounded ', and recourse has to be taken to artificial enrichment. Conditions in India are, however, quite different from those in America and there is paucity of information on the practical application of the principles of rice enrichment under tropical conditions. For a nation which is suffering from malnutrition and which cannot be made to change its dietic habits artificial enrichment may perhaps prove to be the final solution. In recent times a large scale experiment of feeding sections of population with enriched rice has been undertaken in the Philippines, and it is claimed that the incidence of *beri-beri* has gone down in the areas where the experiment has been going on.

CHAPTER XX

PROBLEM OF RICE YIELD IN INDIA

Rice growing conditions vary

RICE is a tropical plant, loving great warmth and high humidity. The average temperature requirement throughout the life of the plant is from 68° to 100°F. and there are no indications that it benefits by any lower temperature at any stage of its development. The other requirements are a plentiful supply of water and bright sunshine during its growth. The best soils suited to rice are heavy loams and clays not too well drained. Outside China, India has the largest area but the diversity of conditions under which rice is grown in India is perhaps present nowwhere else. We have at one extreme the deep water rices of Assam and Bengal growing in 15 to 20 feet of water and at the other extreme, there are rices grown as a dry crop with 25 to 30 inches of rain. Though it does best in heavy loams it is actually grown in poor sandy soils, shallow laterite soils as well as in very heavy clays. Rice can tolerate acidity and alkalinity in soils, the range of PH being 5.0 to 8.5. Rice is grown on lands almost at sea-level as in the river deltas, in lands even below sea level with protective embankments and in altitudes of 3 to 5 thousand feet above sea level. There are rices which can mature in 80 days and there are others which take full 7 months to mature. There are rices grown in different seasons, spring, summer and autumn and in certain parts of the country rice can be seen standing in the field all through the year. It is this diversity of conditions that is responsible for the large number of distinct forms, running into thousands and the great range in level of production.

Acre yield is low

The average yield of rice in India is low being about 800 lb. of cleaned rice per acre. This is roughly about a fourth of the yield in Spain and Italy, one-third of that in Japan and half of those in the U.S.A. and China. The only other countries where similar low yields are recorded are Burma, Siam, Malaya, Ceylon, Indo-China, etc. all concentrated in South East Asia. At the research stations and in demonstration farms the recorded yields are often twice or three times this figure. In recent years the Indian Council of Agricultural Research had conducted crop cutting surveys by a special sampling technique in different rice provinces, and the acre yield has been found to vary from 442 to 1085 lb. It is clear, however, that the survey figures do not push up the acre yields to any considerable degree. There has been considerable amount of research in this crop on the botanical and agronomical side during the last 2 to 3 decades and that the position of acre yields is still unsatisfactory is very discouraging.

Various reasons are given for the low yields in India and they are : (i) more than three-fourth of the rice area has no irrigation facilities and has to depend upon the visicitudes of the monsoon, (ii) the area is so extensive that portions not particularly suitable to the crop are devoted to it, (iii) the practice of applying manure to the soil does not obtain at all with the result that the soil fertility has become stabilized at a very low level, and (iv) the research results have not reached the doors of the person who needs them, i.e. there is a big gap between research and extension. To the above may be added other reasons which are economic, namely, the Indian farmer is poor, illiterate and conservative and his holding is small and there is no incentive in him to produce more. Most of the reasons mentioned here apply equally to other rice countries of South East Asia. The small size of the holding has however not stood in the way of obtaining higher acre yields in China and Japan.

Rice growing conditions in the important provinces

In Bengal less than 10 per cent of the area has irrigation facilities. While the soil in the gangetic delta may be suitable for rice, in the north and south of the province, the soil is too open and not ideal for rice. At the lower end of the delta the land is subject to salt water inundation during high tides and this often affects the rice crop. The low acre yield is thus due, not only to the growing of the crop very extensively in areas of varying suitability, but also to the dependence of a major portion of the rice area only on rainfall. With the dependence on the monsoon the preparation of land is not thorough, and over a considerable portion of the area the crop is directly sown and not transplanted.

In Madras over 70 per cent of the area is protected by irrigation facilities. The bulk of the rice area and the most important from the view point of production lies to the east coast of the province and the concerned irrigation systems depend for their supply on a well distributed south-west monsoon. Though in normal years the water supply may be timely and sufficient, in certain years the supply becomes precarious in the beginning of the season. Early planting which is conducive to bigger yields becomes impossible when the supply is not sufficient. The sampling survey conducted in recent years in the deltaic tracts of this province has shown that the yield falls in the lower portions due both to late planting and to want of drainage. Portions of the area dependent on north-east monsoon often suffers when the monsoon fails. The soils in this province vary from loams to heavy clays and are for the most part suitable for rice except in the western coast where the soil is of lateritic origin and rather shallow. Over 90 per cent of the rice area in the province, the practice of transplanting obtains.

Bihar has got 30 per cent of its rice area protected by irrigation facilities. While the soil in South Bihar is heavy and suited to rice, the soil in North Bihar is light alluvium and not too good for rice. The soil of the Chota Nagpur region is poor and gravelly and the rains here are not also always sufficient for a good rice crop. The yield is rather poor in the latter two regions and the crop is generally broadcast here.

Only 8 to 10 per cent of the rice area in United Provinces has irrigation facilities and 70 per cent of the area is broadcasted. The soil in the north-west is gravelly and porous and the crop has to depend on a copious rain. It is only the flat central portion that has alluvial soils is suitable for rice. Because of the short rainy season very early varieties have to be sown and these invariably suffer from insect damage.

In Central Provinces and Berar, rice is exclusively a monsoon crop and only 20 per cent of the area has irrigation facilities. The soils particularly suitable to rice are to be found only in part of the Chhatisgarh division.

Over 75 per cent of the area is directly sown and the success of the crop mainly depends upon adequate and well distributed rainfall.

Assam has irrigation facilities for only 12 per cent of its rice area. While a steady and not too heavy a monsoon brings in a fair harvest, any upsetting of the balance may mean devastation of large areas, because the deep water rices are grown to a considerable extent here.

In Orissa nearly 25 per cent of the area has irrigation facilities from the Mahanadi and Rishikulya systems. The supply in these systems is, however, not plentiful and is often precarious when most needed by the crop. Even where irrigation facilities are available, the majority of the land is directly sown and not transplanted. The soils also vary very much in their suitability to rice, there being portions of lateritic origin and very shallow in nature.

The rice area in Bombay, confined to the strip of land between the Arabian sea and the Western Ghats, depends entirely on South West monsoon and the soils are not of the heavy type suitable for rice. It is the copiousness of the monsoon rains that support the crop.

Sind which hardly gets 10 inches of rain in the year has to depend mainly on the Indus irrigation system for its rice crop. The soils though alluvial have a low water holding capacity and are deficient in organic matter.

Latitude and rice production

According to available information the original home of rice is South East Asia in the tropics and we have evidence that rice was introduced in the sub-tropical regions of Europe and the New World in recent times. It is possible rice might have originated independently in S. China also and spread to other sub-tropical regions of Asia. Though the two groups of rices grown in the tropical and sub-tropical regions belong to the same species, *O. sativa*, they belong to two different geographical races and have distinct characteristics of their own.

Rice is grown in the sub-tropical regions also up 50° latitude North and 40° latitude South. Comparing the acre yields of rice in the tropical and sub-tropital regions, it is generally found that they are very much higher in the latter than in the former. While part of the increased yields obtained in the sub-tropical regions may be accounted for by the practical application of research findings as in Japan, Korea and the United States of America, the higher yields obtained in China and in some of the Latin American countries cannot be so explained. In Italy and Spain the cultivation practices differ from those of India only in the use of large amounts of artificial fertilizers. In India itself, the rice areas of North India are situated just above the tropics while the rice area of peninsular India comes within the tropics. On the analogy of other countries one should expect higher acre yields in North India than in peninsular India, but the actual position is just the reverse. Madras, which records highest acre yields among the Indian provinces, lies in peninsular India. There is, however, this situation that 70 per cent of the rice area in Madras is irrigated and a much larger area is grown with improved varieties than in other provinces to explain or account for the higher yields. Java which lies in the middle of the tropics also records a higher yield per acre than in other countries and the case is analogous to that of Madras. If the position of a rice area outside the tropics is conducive to greater production there should be greater scope to step up yields in North India by the application of improved technological practices in the cultivation of the crop.

Rice in sub-tropical regions is grown in summer with long days and bright sunshine with no atmospheric disturbances of any kind. The harvests finish before the cold weather sets in. In the tropics however, rice is mainly a monsoon crop with cloudy weather and not much sunshine as in the sub-tropics and the bulk of the harvests come in winter. One should naturally expect the photosynthetic activity to be at its optimum in the sub-tropics. It may be mentioned that while the acre yields in the deltaic regions of South India are generally higher than elsewhere, the highest acre yields are obtained in some of the central districts of Madras where in small areas rice is grown as a summer crop with lift irrigation. Acre yields comparable to those of Spain and Italy are not uncommon here. The case of Sind is again different. Rice is here grown when there are no rains nor cloudy weather, but the acre yields are not high. That the photosynthetic activity of tropical and sub-tropical rice may be different follows from the fact that while there is greater vegetative development in the tropics contributing to a larger production of straw, the proportion of straw to grain is comparatively less in the sub-tropics. The rice crop in most of the sub-tropical countries is very short in straw. Rains may not be necessary at all for a high yield in rice, if sufficient water by irrigation can be given to the crop as and when the crop needs it. In fact, in spite of the higher acre yields, the rice areas of sub-tropical regions depend more upon irrigation than upon rainfall.

Temperature and rice production

In addition to differences in length of day between the tropics and sub-tropics there is also difference in atmospheric temperature during the rice cropping season between the two regions. Under Indian conditions the crop is seldom successful where the mean temperature during the growing season is less than 75°F. The optimum range is considered to lie between 70° to 100°F. While with sufficient water supply it can stand even higher temperatures, it cannot tolerate too much cold during the growing season. In sub-tropical regions like Japan and Spain, the summer temperature is about 70°F, during the rice season. The total temperature required to mature a crop (the sum of the daily mean temperatures throughout the growing period) is about 3000° and 4000° in the sub-tropical countries, whereas, the total temperatures for rices of similar duration grown in India are about two to three times this figure. If long days associated with comparatively low temperatures are the conditions necessary for high yields in rice, we cannot possibly have these conditions in India except probably in high altitudes. The only experience we have in India is that some of the Chinese varieties grown in Kashmir under an elevation of 4—5000 feet above sea level with temperatures varying between 70° to 80°F. during the growing season do give high yields of 4,000 to 5,000 lb. grain in husk, while the same varieties grown in the plains (Cuttack) with temperatures of about 90°F. the yield is only half of the above. In addition to temperature, the day length is also slightly higher in Kashmir than in the plains due to latitude. This is the only instance where large differences in temperature combined with a small difference in day length can account for large differences in yield.

While these considerations may for the present have to remain as mere speculations, there is this fact already established that acre yields comparable to those in sub-tropical regions can be obtained in parts of India, particularly in South India. It only remains to investigate what stands in the way of the practices responsible for high yields in these areas being adopted elsewhere.

'Grow More Food' campaign

India with its large and ever increasing population has never been self sufficient with regard to its rice requirements. The deficit of 6 to 10 per cent of its own production was always met by imports, chiefly from Burma. The food position in India had become particularly serious since the last 3 to 4 years. Food import at the present price levels which are anywhere from 300 to 400 per cent above the prewar level is proving a big drain on the financial resources of the country. Realizing the importance and urgency of the problem of stepping up production inside the country, a 'grow more food' campaign was started in the different provinces and this campaign is being liberally financed jointly by the Central and Provincial Governments. Attempts to increase production are made in two directions, (1) by bringing more area under cultivation and (2) by increasing the acre yields in present areas.

Extension of area and improving water facilities

With regard to extending rice areas in India it is a matter of experience that unless there is a cheap source of water supply and a soil of good depth, rice cultivation does not pay as much as do other crops under similar treatments. In the case of new areas to be brought under cultivation we cannot expect satisfactory outturns in the first few years. It may take a period of three to five years before optimum yields can be obtained. Starting of new irrigation projects, mainly to bring more area under rice or occasionally to improve the water facilities for the existing rice area, should be the sure way of increasing production though the initial expenditure may be heavy. New river projects to improve the existing conditions in United Provinces, Bihar, Bengal and Orissa should be particularly valuable to improve the existing low yields. Small improvements or even minor adjustments in the existing irrigation systems might help to increase the area under the crop, mainly by growing two crops in one year in a certain percentage of the area where only one crop is at present grown. A good proportion of irrigated rice area in Peninsular India is commanded by tanks classed under minor irrigation projects. Due to past neglect these tanks in several cases have become silted up and are not functioning properly. A survey of the tanks and resuscitating them might help. In some cases provision of small tanks or wells which could be used to raise nurseries in time to transplant the crop as soon as the monsoon begins or canal water is available can increase yields. Sometimes it happens in rainfed tracts that the standing rice crop suffers from water shortage by the early cessation of the monsoon though there may be plenty of water flowing in the rivers and canals nearby, with waterlevel some few feet below the level of the level of the fields. Installation of river pumping sets of suitable capacities could relieve the situation. In fact such sets are likely to be particularly valuable to rice areas in parts of the United Provinces, Bihar and Bengal. So far as rice is concerned, the availability of water in times of need is of such overriding importance that this should receive the first priority.

Sea inundated areas

While considering irrigation projects the large inundated areas on the coastal regions of Bengal, Orissa, Madras and Bombay where rice is now a precarious crop may also receive attention. While rice botanists should be able to suggest varieties suitable for these conditions, making the areas safe for rice cultivation is essentially an engineering problem involving perhaps large capital outlay but it is still a problem worth investigating from the view point of the ultimate success in increasing the production within the country.

Increasing acre yields

This can be considered under several heads such as improving water facilities, agronomic practices, better seed and prevention or reducing losses due to physiological causes, pests and diseases. The question of water has already been dealt with. Agronomical practices can be split up into cultural and manurial treatments.

Cultural practices

The cultural practices at present followed in any tract are to a large extent dependent on the existing water supply. The preparation of the land is done either in the dry or wet condition according as the crop is sown direct or transplanted. In the former case, a small improved iron plough should do the work more satisfactorily than the ordinary wooden plough. In the later case, where the main principle is to puddle the land thoroughly, i.e. breaking up the soil particles to a fine condition under water, the efficacy of an iron mould board plough is often questioned. While this may be so, there is no doubt that the small mould board plough, of which there are several types available in the country, does the work more efficiently when the field happens to be overgrown with weeds. While in lighter soils repeated ploughings, either in dry or wet condition, may be beneficial, too many ploughings are unnecessary or may even be harmful in heavy soils. Improvements in cultivation practices in wet condition could, however, be made by the use of the special puddlers used in Madras. Where the soil is not too heavy the puddler does the work more satisfactorily and expeditiously than the plough.

Mechanization by the introduction of tractors, harvester and binder has at present not got much scope in concentrated rice areas where holdings and the size of fields are extremely small. Such mechanization would be possible only in large holdings or in collective farms. Experience from other countries where rice cultivation is highly mechanized tells us that such mechanization to be a success must be complete, i.e. should do away with manual labour for every operation. While tractor ploughing is a necessity for opening new areas and bringing them under cultivation, its use in well established rice areas has only a limited scope. Large concentrated rice areas under present conditions do not offer great scope for industrial development, and these are the areas which are most heavily populated. While it may be advantageous to make a portion of the population less dependent on land, large scale mechanization should create social problems of providing employment to displaced persons.

In India wherever high acre yields are obtained the practice of transplanting in preference to direct sowing obtains. This applies to other

Asian countries as well. Available experimental evidence with rare exceptions, shows that a transplanted crop yields better than a directly sown crop. It also results in saving of seed. Direct sowing is still practised in the case of (1) short duration crops, (2) where the land is poor and the yield is likely to be low, (3) where there is labour scarcity in the rice season and (4) where sufficient water is not available to prepare the puddle in time. It has been found in experiments that direct sowing in lines either in the dry or wet condition is better than broadcasting and that it also results in some economy of seed sown. Line sowing in wet condition is however not easy and will require special implements designed for this operation. The main difficulty with direct sowing is the abundance of weeds which are however controlled in transplanted fields.

Manuring practices

Next in importance to water, application of manures and fertilizers offer the most scope for increasing per acre outturns. Application of manures to rice is seldom practised in the country with the result that the fertility of the soil has become stabilized at a low level. Experiments, that have been conducted during the last 20 to 30 years, do show the great need for the application of nitrogen in some form or other. There is no place in India where the application of nitrogen has failed to give a response. Twenty pounds of nitrogen per acre would appear to be the minimum dose to give profitable returns. The great value of bulky organic manures like, green manuring, composts, bone meal and oil cakes for rice is well established. The only mineral fertilizer that has given satisfactory responses in rice is ammonium sulphate. At the present price level of rice grain, farmers have become extremely fertilizer minded and there is no doubt that the use of ammonium sulphate to rice has come to stay unless the price of rice falls again to an uneconomic level. Available experimental data do however point out that in tropical soils generally deficient in organic matter, dependence on mineral fertilizers alone for increasing production may not be advisable. Green manuring for wet rice, wherever it can be practised, is the best and cheapest source of providing nitrogen to rice. There is evidence that any organic matter, green manure, composts, cattle dung, oil cake, bone meal applied in conjunction with small doses of ammonium sulphate is the best method of fertilizing rice fields. Another interesting information that has come out of the manurial experiments is that the response to fertilizers is greater in soils which are inherently more fertile and where the level of yield is generally high.

With regard to phosphates available, experimental data do not indicate a large response as in the case of nitrogen except in isolated tracts. The response even where it is present is of the order of only 8 to 10 per cent increase in yield for an application of 30 to 40 lb. of P_2O_5 per acre. The general phosphate deficiency indicated in most rice soils and the absence of response to the application of phosphates is hard to explain. More intensive investigations would appear necessary. But we cannot afford to drop phosphates entirely wherever phosphate deficiency is indicated. The application of bulky organic manures in conjunction with ammonium sulphate does not ignore the phosphates altogether.

The results of manurial experiments available in the country refer only to those conducted in Government Experimental Stations where the level of yields is much higher than under cultivators' conditions. With the general finding that the response to manures is higher in soils of greater productivity, the same response may not be obtained in cultivators' fields. There is, however, sufficient local experience already gained with manuring practices on cultivators' conditions, and there is no risk involved in the recommendations being made as part of the 'grow more food' campaign. To be able to draw definite manurial schedules for each tract, on the basis of research, we shall have to carry out extensive trials of a simple type on cultivators' fields in each of the tracts. This is an urgent necessity. While satisfactory increased yields have been obtained by the application of manures in the 'grow more food' campaign in some areas, such yield increases are not realised in others. The utility of manures depends upon other factors also, such as the conditions of the soil, water facility, season and the variety of rice. It should be necessary to make a more elaborate survey of the area and obtain information on various points before we can explain why there is no response to manures under particular conditions [Stewart 1947]. It has to be remembered that more critical information on the soils through which alone the plant can utilise the manure is still lacking in India. Sufficient attention has not been paid to inherent differences in the soils in conducting manurial trials. This is a lacuna that needs attention at the earliest possible time. It is hoped that suitable action will be taken to enable the present knowledge on manuring rice being put to the maximum benefit under cultivators' conditions.

Using seed of improved varieties

Unlike in earlier years the multiplication and distribution of improved seed now forms an essential part of the 'grow more food' campaign in every province. No new variety is released for general distribution unless it gave a 10 per cent increased yield over the variety it is intended to replace. In fact, most of the varieties actually released have recorded yield increases of even 20 per cent and more over the local varieties. In some cases these improved varieties, possess other useful characters in addition, such as earliness, good quality grain and better straw. The recent crop cutting experiments carried out by the Indian Council of Agricultural Research in seven districts of Madras have shown that the improved varieties give a 20 per cent increase over the local ones.

Plant breeding has been an outstanding success in several provinces. For example in Madras with a large number of breeding stations, one in each of the important tracts, there are now improved varieties available for most of the tracts within the province. It is now estimated that 30 per cent of the area in the province is covered by improved varieties. Because of the limited adaptability of rice to varying conditions, breeding has to be done in the tract itself. It will not be possible to cater to the needs of different tracts from work at one central station. This principle has not been sufficiently recognised in many of the provinces. The ideal arrangement should be to have as many stations as the number of individual tracts with varying conditions warrant. There is no doubt, that to carry out breeding work more thoroughly and more intensively for the country with 70 million acres under rice, we shall require several more breeding stations and competent breeders to man them than what we have at present. The magnitude of the work needs no emphasis. Varieties superior to what is commonly grown by the cultivators have to be evolved for millions of acres on which unselected mixed types still continue to be grown. It may be mentioned for comparison that in Japan with seven million acres under rice, and where there is not so much diversity as in India, there are besides the Imperial Experimental Station six secondary stations and 10 regional stations devoted to rice breeding.

Breeding for disease resistance

Although increased yield is the main consideration in breeding new varieties, other aspects of research to which considerable attention is being devoted in some of the provinces include breeding for disease resistance and resistance to undesirable physiological characteristics. That pathological diseases take a heavy toll of this important food crop in this country is well recognised. Of the diseases, some occur in a chronic form causing what would appear to be inequitable losses to individual growers but in the aggregate are responsible for several thousand tons. There are other diseases which break out periodically in an epidemic form causing loss of crop to the extent of 50 to 80 per cent. It is the control of this latter category of diseases that holds out promise of substantial increase in the production of rice in the country, and breeding for resistance offers the greatest scope. To get complete success in such breeding programme, all the fundamental information about the particular disease, its pathogenecity, optimum conditions for infection, alternate hosts and different physiological races should be available. Such intensive studies have been taken up only in recent times. Work in Madras during the last 15 years has given striking results in that a range of new varieties resistant to one of the important diseases, *Piricularia oryzae*, even under the most adverse conditions and which are otherwise good yielders has been obtained by suitable hybridization. This is a notable example of successful cooperative research between the breeder and the mycologist. If, however, this achievement should bear quick results a system should be evolved by virtue of which *Piricularia* resistant rices are grown exclusively in all tracts where the disease is known to occur in an epiphytotic form. This work is yet to be undertaken in other provinces.

Another important disease of rice prevalent all over the country and which needs intensive studies as in the case of *Piricularia* is *Helminthosporium oryzae*. This can appear in a severe epidemic form in some areas and there are reasons to believe that this disease was partly responsible for the serious loss of crop that occurred in Bengal during the famine year.

There is still another important disease of rice common in many countries, *Fusarium moniliforme* which by virtue of its seed-borne nature is a potential danger to rice production. Work in Madras has shown that dressing of seed before sowing with an organomercury compound effectively controls the same. It does not cost more than 4 as. per acre to do this. Such seed treatment can also control losses at least in the preliminary infection of the seed borne disease, *Helminthosporium*, which causes considerable damage in the nursery stage in some of the provinces. Such seed treatment is often conducive to better germination by improving the viability of seed.

With regard to insects the main limiting factor against the use of remedial measures in the field crop is the high cost of the insecticides. The position is however changing and one may expect in the near future to have at his disposal cheaper insecticides, and until this happens other methods of control are the only way. There is a large scope for investigations on biological control also, particularly in the case of stem borer, the worst pest on rice. The question of pests on stored grain comes, however, under a different category and there are already available excellent insecticides, by the proper use of which, losses can be entirely prevented.

Breeding for better physiological and other characters

There are other aspects of breeding to which attention may be drawn. Losses to the crop often occur due to the shattering of the grain from the panicle, premature lodging of the crop due to weakness in the straw and various forms of sterility of the spikelets. Work in Madras has shown that all these characters are controlled by genes and can be dealt with in breeding programmes. Among such physiological characters may be included resistance to floods and resistance to drought. Varieties somewhat resistant to floods have been obtained by selection in Assam and Orissa. Mention may be made of the success achieved by hybridisation in combating the menance of wild rice, *O. sativa* var *spontanea,* in the Central Provinces and Berar and Bombay. This dealt with elsewhere in this monograph has resulted in saving nearly 2 per cent of the production in the Central Provinces and Berar. That even resistance to some insect pests can be tackled as a breeding programme is exemplified by the work in the United Provinces of breeding for resistance to the ear fly, *Leptocorisa varicornis*.

Earliness a valuable character

One of the physiological characters which can be successfully tackled in the breeding programme is earliness. Earliness would be most welcome provided that the earliness is not associated with loss in productivity. Results already available in Madras and Bengal clearly show that this can be done. In fact, some of the biggest yields have been recorded in varieties of 100 to 120 days in duration. The present food crisis in the country should particularly stimulate this line of research. Growing of early varieties would facilitate maximum use being made of the available water supplies. It may be possible to grow two short crops in succession or where the water supply is limited to grow a rice and a pulse crop after it. Moreover, early varieties give generally a better response to fertilizers.

In connection with breeding it has to be mentioned that available experience in Madras does point out that the greatest response to intensive manurial treatment is obtained by growing the improved varieties. To get the maximum increase in production growing of improved varieties and manuring should go together. It would appear that in Japan improved varieties are often of no use if sufficient quantities of fertilizers are not applied, and best results are not obtained from fertilizers if improved varieties are not used. This is probably the reason why high yields are obtained in the experimental stations and not in cultivators' fields which never get any manure. This has to be remembered in the 'Grow More Food' campaign.

Other aspects of breeding

Connected with breeding there are one or two points to which attention may be drawn. While the available results in rice breeding are substantial, there is considerable scope in several areas for intensification of the same by adopting improved and more rational techniques. Moreover, in some of the areas the testing of improved varieties has not gone very much beyond the experimental stations. It is only by testing them in cultivators' fields we can make definite recommendations to the cultivator. These aspects need attention.

It is recognized that coarse varieties and those with coloured kernel are generally more hardy and give greater yields. From the nutrition point of view also such varieties are to be preferred to fine white rices. A perusal of Chapter X does show, however, instances where breeders have been attempting to replace commonly grown coarse rices by fine ones. The better plan would have been to evolve more prolific strains from out of the local coarse varieties. Under present conditions, and to satisfy the large majority of the population, yields must remain the main objective of breeding, and there appears to be no justification to undertake breeding for quality where such quality only means fineness of grain, loss in nutritional value and often loss in productivity also.

Growing an improved variety costs the cultivator no additional expense and no difficulty has been experienced anywhere about the cultivator being unwilling to take up the improved variety when once he is convinced of its superiority. Any expenditure on plant breeding should give returns several fold. It is in fact the results of plant breeding that form the chief plank on which most of the extension work of the Agricultural Departments depend. Breeding is a continuous process and the advances in the related science such as genetics, cytology, physiology, pathology, statistics, etc. are creating an ever-increasing and wider field for the plant breeder to intensify his work upon. It may be pointed out that in precarious tracts which form a large percentage of the total area, the evolution by breeding of ecological types suitable to particular conditions should form the only means of increasing production in such areas.

Conclusion

The various aspects of increasing acre yields have been dealt with under climate, soil, water, improved varieties, improved cultural practices and prevention of losses. Comparing India with two countries which produce very high acre yields namely, Japan and Italy, the essential differences appear to lie in climate and cultural practices—particularly with reference to application of fertilizers. Climate cannot be changed, but that this need not stand in the way of increasing acre yields in India has been demonstrated by the records of yields comparable to any of the sub-tropical countries in experimental stations and demonstration farms. While in India there is no general practice of fertilizing the field, in Japan and Italy the application of fertilizers to the extent of 60-80 lb. of nitrogen and 50-60 lb. of each of $P_2 O_5$ and K_2O per acre is a common practice. Even in India there are areas where such heavy doses of fertilizers can be profitably applied, but what is lacking is more precise information on the variations in the soil and the suitable quantities of fertilizers that may be applied according to such variations. Scientific information on these points is, however, not lacking completely. There is also sufficient experimental data available on other aspects of production. That India has not been able to increase her production substantially is certainly not due to lack of experimental research or scientific knowledge. The most significant reason appears to be the wide gap between research and extension. The cultivator does appreciate the value of scientific knowledge but still he cannot make use of it. Increasing production would ultimately depend upon understanding the reasons why he does not make use of this knowledge and remedy his position. Mechanization, as is sometimes believed, is not synonymous to greater production. The problem is essentially that of the small peasant and it is a proper appreciation of his needs and circumstances that should provide a solution.

REFERENCES

Abe, T., (1935). On the relation of atmospheric humidity to the infection of the rice plant by *Piricularia oryzae*. *Exp. Stn. Rec.* 72, 202.

Adair, C. R., (1936). Studies on growth in rice. *J. Amer. Soc. Agron.* **28**, 506-513.

—— (1941). Inheritance in rice of reaction to *Helminthosporium oryzae* and *Cercospora oryzae*. *Biol. Abs.* No. 16228.

Akemine, M., (1925). On the inheritance of dwarf habits in rice (In Japanese) *Abs. in Jap. J. Bot.* 3, 77.

—and Hoshika, Y., (1939). Intervarietal difference and effect of environmental factors in respect to sterility. *Spl. Bull. Expt. Farm, Hokkaido, Imp. Uni. Sapparo,* No. 7.

Alam, M., (1932). Problem of rice breeding with particular reference to Bihar. *Agri and Livestock in India.* 1, 497-511.

—— (1935), (1936), (1939) & (1940) Annual Report of the rice research Station, Sabour, for 1934-35, 1935-36 1937-38, 1938-39 and 1939-40.

—— (1939). Grain quality index of rice. *Proc. 24th Ind. Sci. Cong. Abs.* No. 148 (Agriculture).

—and Trivedi, S., (1934). Studies in rices of Bihar and Orissa. *Proc. 24th Ind. Sci. Cong. 1934. Abs.* 38.

Anandan, M., (1928) & (1933) *Madras Agric. Stn. Repts.* Aduturai, 1932-33 and 1927-28.

—— and Krishnaswamy, V., (1934) Barren sterile. A new mutation in rice and its inheritance. *Curr. Sci.* 3, 21-23.

Anderson, E., (1939, a) Recombination in species crosses. *Genetics* 24, 668-98.

—— (1939, b) The hindrance to gene recombination imposed by linkage. *Amer. Nat.* 73, 185-8.

Anonymous, (1917). History of rice. (Reprinted from the Rangoon Gazette, 5th Nov. 1917). *Agric. J. India,* 12, 471-2.

—— (1930). Literature on lodging in cereals. *Bull. Imp. Bureau, Pl. Genet.* 633. 1-2. 183.

—— (1935). Vernalisation and phasic development of plants. *Imp. Bur. Pl. Genet. Bull.* No. 17.

—— (1938). *Final report of work done on quality in rice at Coimbatore.* I. C. A. R. publication, New Delhi.

—— (1940). *Seed distribution in India.* Government of India publication.

Ashby, E., (1930). Studies in the inheritance of physiological characters.

—— (1932). I. Physiological investigation of the nature of hybrid vigour in Maize. *Ann. Bot. (Lond.)*, 44, 457.

—— (1932). Studies in the inheritance of physiological characters.
II. Further experiments upon the basis of hybrid vigour and upon the inheritance of efficiency index and respiration rate in Maize. *Ann. Bot. Lond.* 46, 1007-1032.

Aykroyd, W. R., (1932). The effects of parboiling and milling on the antineuritic vitamin B_1 and phosphate content of rice. *J. Hygene* 22, 184-92.

—— Krishnan, B. G., Passomore, R. and Sundararajan, A. R. (1940). The rice problem in India. *Ind. Med. Res. Mem.* No. 32.

Balajirao, T. K., (1926). A note on some phases of flowering in Tanjore District. *Mad. Agric. J.* 14. 245-52.

Banerjee, K. C., (1936). Studies in tiller variation. *Ind. J. agric. Sci.* 7, 863-72.

Beale, R. A., (1927). Scheme of classification of rices found in Burma. *Agric. Res. Inst. Pusa. Bull.* No. 167.

Bhalerao, S. G., (1926). Morphology of the rice plant and of the rice inflorescence. *J. Ind. Bot. Soc.* 5, 13-15.

—— (1930). The grain shedding character and its importance. *Agric. Res. Inst. Pusa, Bull.* No. 205.

Bhide, R. K., (1922). A case of sterility in rice flowers. *Agric. J. Ind.* 17, 584-86.

—— (1925). Our experiences in crossing different varieties of rice at Karjat. *Agric. J.* India, 20, 280-84.

—— (1926). Inheritance and correlation of certain characters in rice crosses. *Poona Agric. Coll. Mag.* 18, 76-85.

—— and Bhalerao, S. G., (1927). The Kolamba rice of North Konkan and its improvement by selection, *Mem. Dept. Agric. Bot. Ser.* 14, 237-76.

Birkinshaw, F., (1940). A Review of field experiments on paddy in Malaya. *Mal. Agric. J.* 28. 507-16.

Bose, S. S. and others, (1936). Frequency distribution of plot yields and optimum size of plots in a uniformity trial in Assam. *Indian J. agric. Sci.* 6, 1107-21.

Bruman, A. J., (1937). The place of vernalisation in plant breeding. *Biol. Abs.* 11, No. 17848.

Butler, E. J., (1913). Diseases of rice. *Agric. Res. Inst. Pusa, Bull.* No. 34.

—— (1918). Fungi and Diseases of Plants. Thacker Spink & Co.

Capinpin, J. M., (1923). Correlation within pure lines of rice. *Phil. Agrst.* 13. 3-14.

— and Punyasingh, K. (1938). A study of varietal crosses and hybrid vigour in rice. *Phil. Agrst.* 27, 255-77.

Carle, E., (1925). Pedigree selection applied to the rice variety in Indo-China. *Int. Rev. Sci. and Prac. of Agric.* 11, 716-7.

Catamby, A., (1913). Effect of size of grain on frequency, number of grain, etc. *Phil. Agric. Rev.* 6, 88.

Chakravarty, S. C., (1937) (1938), (1939) & (1940). *Report of rice Research Station, Chinsurah, Bengal* for 1937-38, 1938-39, 1939-40.

Chalam, G. V., (1942). An anatomical study of the shedding and non-shedding characters in the genus *Oryza*. *J. Ind. Bot. Soc.* 21, 339-49.

Chao, L. F., (1928, a). Linkage studies in rice. *Genet.* 13, 133-69.

—— (1928, b). The disturbing effect of the glutinous gene in rice on Mendelian ratio. *Genetics*, 13, 191-225.

—— (1934). Linkage studies in rice. *J. Agric. Res. Nat. Cent. Univ. Nanking*, 1, 13-63.

Chatterjee, D., (1947). Botany of the Wild and Cultivated Rices. *Nature*. 160, 234.

Chevaliar, A., (1932). New contribution to the systematic study of genus Oryza. *Rev. de Botanique* 12, 1014.

—— (1935). On the duplicate origin of cultivated rices and the West African centre of distribution, *Pl. Breed. Abs.* 7, No. 1267.

Chevalier, R. J., (1932). Revue de Botanique. New contribution to the systematic study of the genus *Oryza*. 12, 1014, *Pl. Breed. Abs.* 3, No. 433.

Chiapelli, R., (1930). On natural crossing in rice and a method of encouraging it. *Pl. Breed. Abs.* 1, No. 371.

—— (1936). An interesting mutation in rice. *Pl. Breed. Abs.* 7, No. 993.

Codd, L. E. W., (1934). A case of chlorophyll deficiency in rice. *J. Hered.* 26, 85-7.

—— (1935). Vernalisation and its application to rice. *Trop. Agrst.* 84, 36-7.

Codd, L. E. W. and others (1933). Rice in British Guiana, 1927-32. *Rice Bull.* No. 1. Dept. Agri. British Guiana.

Copeland, E. B., (1924). Rice. MacMillan & Co., London.

Dave, B. B., (1937) (1938) (1939) & (1940). *Ann. Rept. Rice. Res. Stn.*, Raipur, Central Provinces, 1936-37 to 1939-40

De Candolle, (1886). Origin of cultivated plants.

Dixit, P. D., (1941). *Ann. Rept. Rice Res. Scheme*, Orissa, 1940-41.

East, E. M., (1936). Heterosis. *Genetics*, 21 375-97.

Engledow, F. L., (1923). The inheritance of glume length in a wheat cross. *Jour. Genet.* 10 and 13.

—— (1933). The problem of cereal yield. *Proc.* World's Grain Exhibition and Conference, Regina, Canada, 2, 9-15.

—— and Ramiah, K., (1930). Investigation on yield in cereals, VII. A study of Development and Yield of wheat based on varietal comparison. *J. Agric. Sci.* 20, 265-343.

—— and Wadham, S. M., (1923-24). Investigation on yield in cereals. Indian *J. Agric. Sci.* 13, 390-439 and 14, 325-45.

Enomoto, N., (1929). Mutation of the endosperm character in rice plant. *Jap. J. Bot.* 6, *Abs.* 4.

Erygin, P., (1934). Physiological and Biochemical study of upland and low and rice. *Bul.* No. 6, Central Experimental Station, Krasnodor, U. S. S. R.

Fikry, M. A., (1937). Influence of size and weight of seed upon growth and yield. *Biol. Abs.* 11, No. 16824.

Fisher, R. A., (1936). The use of multiple measurement in taxonomic problems. *Ann.* Eug. 7, 179-88.

—— (1938). Statistical methods for research workers.

Fisher, R. A. and others (1932). The genetical interpretation of statistics of the third degree in the study of quantitative inheritance, *Genetics*, 17, 107-22.

Fruwirth, C., (1908). *Die Auchtung der Landw. Kulturflarzer. Bid.* V, 36.

Fukaki, (1927). On effects of plant nutrients and light on tillering. *Exp. Stn. Rec.* 59, 135.

Gagolinan, V., (1936). A study of the variability and the possibility of isolating Apostol rice strains with strong rachillae. *Phil. Agrst.* 24, 659-77.

Ganguli, P. M., (1940, 1942). *Annual report of the Deep water paddy research station, Habiganj,* Assam for 1939-40, 1941-42.

Ganguly, D., (1945). A note on the occurrence of *Cercospora Oryzae* Mujake on Paddy in Bengal, *Science & Culture* 9, 573-74.

—— (1946). *Helminthosporium* disease of paddy in Bengal. *Sci. Cult.* 12, 220-323. 1946-47.

Gotoh and others (1935). Cytological and genetical studies of Oryza. *Jap. J. Genet.* 11, 130-31.

Graham, R. J. D., (1911), *Proc. Board of Agriculture* in 1911, H. Rice.

—— (1913). Preliminary note on the classification of rice in the Central Provinces. *Mem. Dept. Agric. Ind. Bot. Ser.* 6, 209-29.

Grant, J. W., (1932). Rice crop in Burma. *Burma Agric. Survey* 17.

—— (1935) (1936) (1937) and (1938). *Annual Report of Rice Research Officer*, Burma. 1934-35, 1935-36, 1936-37, 1937-38.

—— and Thein Aung, U. (1941). Growth studies in rice. *Indian J. Agric. Sci.* 11, 380-89.

Grekov, P. I., (1942). Intensified mutation of the embryo of spring wheat with endosperm and its influence on the first generation. *Pl. Breed. Abs.* 12, No. 436.

Gustchin, G. C., (1939). Rice origin and history of cultivation, *Pl. Breed. Abs.* 9, No. 273.

Haigh, J. C., (1934). Vernalisation. *Trop. Agrst.* 82, 214-16.

—— (1934). Vernalisation and flowering in paddy. *Trop. Agrst.* 83, 329-35.

—— (1935). Vernalisation, II. *Trop. Agrst.* 85, 332-36.

—— (1940). Grain and straw weight relationship in paddy. *Trop. Agrst.* 95.

Hamid, S. and Baker, J.A. (1939). Note on attempt to estimate the threshing qualities in paddy. *Mal. Agric. J.* 27, 269-70.

Hann, H. D., (1914). Improvement of rice by selection in Java. *Trop. Agrst.* 43, 26-35.

—— (1933). Inheritance of chlorophyll deficiency *Biblio-genet*, 10, 357-90.

Hanumantharao, K., (1935). A simple device for estimation of shedding. *Mad. Agric. J.* 23. 77.

Hara, S., (1930). On the influence of duration of illumination upon the shooting time and growth of paddy rice. *Jap. J. Bot.* **5**, *Abs.* 57.

Hector, G. P., (1913). Notes on pollination and cross-fertilisation in the common rice plant, *Oryza sativa*, L. *Mem. Dept. Agric. Ind. Bot. Ser.* **6**, **1-10**.

—— (1913). *Proc. Board. Agric. meeting in India*, 1913, Section-Rice.

—— (1916). Observations on the inheritance of the anthocyan pigment in paddy varieties. *Mem. Dept. Agric. Ind. Bot. Ser.* **8**, 89-101.

—— (1922). Correlation of colour characters in rice. *Mem. Dept. Agri. Ind. Bot. Ser.* **11**, 153-83.

—— (1922). *Ann. Rept. of Bengal Dept of Agric.* for 1921-22.

—— (1927). *Ann. Rept. of Bengal Dept of Agric.* for 1926-27.

—— (1930). Agricultural and Botanical classification of rices of Bengal. *Agric. J. Ind.* **25**, 150-53.

—— and Sharangapani, S. G., (1934). Varietal characters and classification of the rices of East Bengal. *Indian J. Agric. Sci.* **4**, 1-80.

Hector, J. M., (1937). *Introduction to the Botany of field crops.* **1**, Cereals. Rice, 272-306.

Hedayatullah, S. (1933). A cytological study of the behaviour of nucleoli in the pollen mother cell. of rice (*Oryza sativa* L.) in the parent plant and in their hybrids. *Pl. Breed. Abs.* **4**, No. 39.

—— (1941). *Annual Report of First Economic Botanist*, Bengal for 1940-41.

—— and Chakravarty A. K. (1941). A comparative study of the mechanical system in five species of the genus. *Oryza. J. Dept. of Sci. Bengal*, N. S. **1**, 21-8.

—— and Sen, N. K.(1941). Preliminary studies on vernalisation. *Proc. 28th Ind. Sci. Cong. Abs.* **44**, (Agriculture).

Hirayoshi, I. (1938). Chromosome number in plant species allied to those of the genus. *Oryza Jap. J. Bot. Abs.* **9**, No. 361.

Holfman, I. C. (1923). Size of sweet corn kernels and evenness of maturity. *J. agric. Res.* **31**, 1043-53.

Horlacher, H. R. and (1932) Killough, D.T. Progressive mutations induced in Gossypium hirsutum by radiations *Amer. Nat.* **67**, 532-38.

Hoshino, Y. (1915). On the inheritance of flowering time in peas and rice. *J. Coll. Agri. Tokyo Imp. Univ.* Sapparo, **6**, 229-88.

Hudson, P. S. (1937). Genetics in its application to plant breeding. *Biol. Rev.* **12**, 285-319.

Hutchinson, J. (1934). The families of flowering plants. II. Monocotyledons. MacMillan & Co.

Hutchinson, J. B. (1937). *Proc. of the 1st Conf. of Cotton Workers in India.* **2**.

—— and Panse, V.G. (1937) The design of Field tests with plant breeding material *Indian J. Agric Sci.* 7, 531-64.

—— and Ramiah, K. (1938). Description of crop plant characters and their ranges of variation, II, Variability in rice. *Indian J. Agric Sci.* **8**, 592-616.

Ichijima, K., (1934). Artificially produced mutations and polyploid plants of rice occurring in subsequent generations. *Jap. J. Bot.* **8**, *Abs.* No. 144.

Ideko, H., (1938). Judging of rice varieties by different types of embryo growth. *Pl. Breed Abs.* **8**, No. 515.

Idsumi, Y., (1937). Investigations in heterosis of rice plants. *Pl. Breed, Abs.* **7**, No. 1265.

Ikeno, S., (1916). On the inheritance of flowering time in rice. *Jap. J. Bot.* **2**, *Abs.* **114-15**.

—— (1919). A text book on genetics (in Japanese). *Jap. J. Bot.* **2**, *Abs.* 114-15.

—— (1919). Experimental genetics, a text book. *Jap. J. Bot.* **2**, *Abs.* 114-15.

—— (1927). A monograph on rice genetics. *Biblio Genet.* **3**, 245-312.

Iliffe, R. O., (1929) *Madras Agric. Stn. Reports* for 1928-29.

Imai, Y., (1928). A consideration of variegation. *Genetics*, **18**, 544-62.

—— (1934). An unstable line of *Oryza sativa* that throws out albinos. *Pl. Breed Abs.* **5**, No. 711.

—— 1935). The effect of X-rays in the production of sterile rice. *Jap. J. Genet.* **10**, 233-36. (*Pl. Breed. Abs.* **5**, No. 711).

—— (1935) (*a*). Chlorophyll deficiency in *Oryza sativa* induced by X-rays, *Jap. J. Genet.* **11**, 157-61.

—— (1935) (*c*). Some observations on chloroplasts. *Biol. Abs.* **11**, No. 5320.

—— (1936). The remarkable low ratios of recessive segregates in Oryza Sativa. *Pl. Breed. Abs.*, No. 6. 908.

Inoue, Y., (1939). Comparison of the cellulose decomposition by culture strains of the rice blast fungus, (*Piricularia oryzae*), *Biol. Abs.* **13**, No. 15850.

Ishikawa, J., (1929). Studies on the inheritance of sterility in rice. *Jap. J. Bot.* **4**, Abs. 24.

Isshiki, S., (1933). On the occurrence and inheritance of sterile rice plants with twisted leaves and narrow leaved ones with open glumes. *Pl. Breed. Abs.* **4**, No. 170,

Ivanov, P. K., (1937). On the diagnosis of frost and heat resistance of plants by their seeds. *Pl. Breed. Abs.* **7**, No. 929.

Jack, H. W., (1923). *Rice in Malaya Dept. Agric. F. M. S. & S.* Bull. No. 35.

—— (1932) Breeding and varietal trials of rice. *Mal. Agric. J.* **20**, 614-30.

Jacobson, H. O., (1916). Correlative characters of rice plant. *Phil. Agric. Rev.* **9**, 74-119.

Jobithraj, S. (1936),(1937). *Ann. Rept. Rice. Stn.*, Berhampore, Madras, 1935-36 and 1936-37.

Jodon, N. E., (1938). Experiments with artificial hybridisation in rice. *J. Amer. Soc. Agron.* **30**, 294-305.

—— (1940). Inheritance and linkage relationship of a chlorophyll mutation in rice. *J. Amer. Soc. Agron.* **32**, 342-46.

Jones, J. W., (1925). Branching of rice plants. *J. Amer. Soc. Agron.* **17**, 619-23.

—— (1926). Hybrid vigour in rice. *J. Amer. Soc. Agron.* **18**, 423-28.

—— (1927). Inheritance of awnedness in rice. *J. Amer. Soc. Agron.* **19**, 830-39.

—— (1928). Polyembroyony in rice. *J. Amer. Soc. Agron.* **20**, 774.

—— (1928) Inheritance of earliness and other agronomic characters in rice. *J. Agric. Res.* 36, 581-601.

—— (1929). Review of the literature on pollination, hour of blooming and natural crossing in rice. (Mimeographed). Office of Cereal Crops and Diseases Bureau of Plant Industry, U. S. Dept. of Agric.

—— (1929). Distribution of anthocyan pigments in rice varieties. *J. Amer. Soc. Agron.* **21**, 867-75.

—— (1930),(*a*). Inheritance of anthocyan pigments in rice. *J. Agric. Res.* **40**, 1105-28.

—— (1930), (*b*). Sterility in rice hybrids. *J. Amer. Soc. Agron.* **22**, 861-67,

—— (1933). Inheritance of characters in rice. *J. agric. Res.* **47**, 771-82.

—— (1936). Improvement in rice. *Year book of Agric.* U. S. D. A. 415-54.

—— and Adair C. Roy (1938), (*a*). A ' Lazy ' mutation in rice. *J. Hered.* **29**, 315-8.

—— and Longley, A. E. (1941). Sterility and aberrant chromosome number in Caloro and other varieties of rice. *J. Agric. Res.* **62**, 381-401.

—— Adair, C. Roy, Beachell, H. M. and Davis, L. L. (1935). Inheritance of earliness and length of kernel in rice. *J. Amer. Soc. Agron.* **27**, 910-21.

Joshi K. V., and Gadkari, M. V. (1923). Studies on the rice plant and rice cultivation. *Bombay Dept. Agric. Bull.* No. 11.

Kadam, B. S., (1932). Mutation in rice. *Nature* **129**, 616-7.

—— (1935), (*a*). A virescent white mutation in rice. *Curr. Sci.* **3**, 301-2.

—— (1936), (*a*). An anthocyan inhibitor in rice. *J. Hered.* **27**, 405-8.

—— (1936), (*b*). Genic analysis in rice I. Grain shedding. *Proc. Ind. Aca. Sci. Sect.* B **4**, 224-9.

—— (1937). Genes for dwarfing in rice. *Nature* **139**, 1070.

—— (1937), (*b*). Heterosis in rice. *Ind. J. Agric. Sci.* **7**,118-26.

—— (1938). Inheritance of root colour in rice. *J. Ind. Bot. Soc.* **14**, 173-8.

—— (1941). Gene analysis of rice II. Chlorophyll deficiency. *Ind. J. Genet. and Pl. Breed.* 1, [illegible].

—— Gadkari, P. V. and Patil, G. G. (1941). A long glume mutation in rice. *Curr. Sci.* 10, 331-3.

—— and Kalamkar R. J. Patankar, V. K. (1937). Estimation of rice yield by sampling. *Curr. Sci.* 5, 533-4.

—— and [illegible], V. K. (1934). Inheritance of chlorophyll in [illegible] rice. *Poona Agri. Coll. Mag.* 26, [illegible].

—— (1938). Inheritance of aroma in rice. *Chro. Bot.* 4, 496-7.

—— Patil, G. G. and (1933). Breeding and [illegible] in Kolamba. *Indian J. agric. Sci.* 3, 377-88.

—— and Patil, G. G. (1934). Natural crossing in rice. *Poona Agric. Coll. Mag.* 25, 53-61.

—— Patil, G. G. and Patankar, V. K. (1936). Double awned spikelets in rice. *Curr. Sci.* 4, 739.

—— and Ramiah K. (1943.) Bibliography of genetics of rice. *Ind. J. Genet. and Pl. Breed.* 3, 125-32.

—— (1943). Symbolisation of genes in rice. *Ind. J. Genet. & Pl. Breed.* 3, 7-27.

Kagawa, F., (1939). A case of inheritance of sterile plants with large grains and their chimeras. *Pl. Breed. Abs.* 9, No. 277.

—— (1940). Studies on the inheritance of a type of large grained partially sterile plant. *Pl. Breed. Abs.* 10, No. 149.

Kanna, B., (1935). Chlorophyll deficiency induced by X rays. *Pl. Breed. Abs.* 7, No. 215.

Kappert, H., (1933). Inherited Polyembryony. *Pl. Breed. Abs.* 4, No. 204.

Kasahara, Y., (1934). *Pl. Breed. Abs.* IV. Abs. No. 425.

Kashiram, and Ekbote, R. B., (1936). Classification of cultivated rices of the Punjab and Western United Provinces. *Indian. J. Agric. Sci.* 6, 930-7.

Kashiram and Sarvayya, C. V., (1934). The development of pigments in glumes and apiculus of rice varieties. *Ind. J. Agri. Sci.* 4, 523-55.

—— (1934). Classification of rices of Bihar and Orissa. *Indian J. Agric. Sci.* 4, 537.

Katayama, T., (1937). Analytical studies of tillering in paddy. *Biol. Abs.* 11, No. 11921.

Kato, S., and Ishikawa, J. (1921). The heredity of the pigments of red rice. *Jap. J. Bot.* 1, Abs. No. 11.

Khadilkar, T. R., (1934). Seasonal fluctuations in the rice plants. *Proc. 21st Ind. Sci. Cong.* Abs. 40.

Kidd, F., and West, C. (1918). Physiological pre-determination. The influence of physiological condition of seed upon the course of subsequent growth and upon yield. *Ann. Appl. Bio.* 5, 112-39.

Kikkawa, S., (1912) Classification of cultivated rices. *J. Coll. Agric. Imp. Univ. Tokyo* 3. 11-108.

Kiesselbach, T. A., (1924). Relation of size of seed to the yield of small grain crop. *J. Amer. Soc. Agron.* 16.

Komuro, H., (1922). Polyembryony in rice. *Bot. Mag.* (Tokyo) 36. 23-4.

—— (1922). On the effect of Rontgen rays upon the growth of *Oryza sativa.* *Bot. Mag.* (Tokyo) 38, 1-2.

—— (1924). Studies on the effect of Rontgen rays upon the germination of *Oryza sativa.* *Jap. J. Bot.* 2. Abs. 47.

Kondo, M., (1928). Pedigree breeding of semi-sterile rice plants. *Biol. Abs.* 2, No. 143.

—— (1930). Spontaneous occurrence of an aberrant rice plant. *Biol. Abs.* 4, No. 3537.

—— and Noguchi, (1922). Correlation between quantitative characters of selected elite plants of rice, wheat, barley and between the same characters of their offspring. *Bot. Abs.* 14. No. 6303.

—— and Ono, M., (1925). One kind of semi-sterility in rice *Jap. J. Bot.* 14. Abs. No. [illegible].

—— and others, (1938). Investigation on photoperiodicity of rice plants. *Pl. Breed. Abs.* 9, No. 84.

Konishi, S., (1933). On physiologic specialisation in rice blast fungus. *Abs. Expt. Sta. Rec.* 72, [illegible].

Kosaka H., Miyashima, I., and Yasukawa, D. (1938). Studies on the response to unfavourable environments of certain varieties of rice plant. *Pl. Breed. Abs.* 8, No. 1516.

Kostoff, D., (1937). Chromosome alterations by centrifuging. *Sci.* **86**, 101.

—— and Kendall, T. (1932) Origin of a tetraploid shoot from the region of a tumour on tomato. *Sci* 76, 144.

Krishnamurti, K., (1937). Scientific report of the *Imp. Inst. Agric. New Delhi*, 1936-37.

Kuwada, Y., (1910). A cytological study of *O. sativa* L. *Bot. Mag.* (Tokyo), 24, 267-81.

Lawrence, W. T. C., (1931) The secondary association of chromosomes. *Cytologia* **2**, 352-84.

Lee, T. C., (1927). Colour inheritance of glume tips and stem nodes in certain rice plants *Jap. J. Bot.* **4**, Abs. No. 33.

Lefroy, H. M., (1906). Indian insect life.

Lord, L., (1929). Improvement of rice in Malaya, Indo-China and Java. *Trop. Agrst.* 73, 323-46.

—— (1929), (*a*). Measurements of the grains of Ceylon rices. *Annals Roy. Bot. Gard.* Peradeniya 11, 165-72.

—— (1929). (*b*). Germination of rice seeds in Ceylon. *Ann. Roy. Bot. Gard.* Paredeniya, 11, 113-23.

—— (1931). A uniformity trial with irrigated broadcast rice. *J. agric. Sci.* **21**, 178-90.

Luthra, J. C., and Sattar, A., (1936). Some studies on the Sclerotial diseases of rice (*Sclerotium oryzae* catt.) in the Punjab. *Indian J. Agric. Sci.* 6, 978-84.

Mahalanobis, P. C., (1934) A preliminary note on intervarietal correlation in rice plant. *Pl. Breed. Abs.* **4**, No. 545.

Mahta, D. N., and Dave, B. B. (1931). Rice breeding in Central Provinces. *Indian J. Agric. Sci.* 1, 351-70.

Majid, S., (1937) (1938), (1939) and 1940). *Ann. Rept. Deep-water Rice Res. Stn.*—Habiganj, Assam, 1936-37 to 1939-40.

Matsura, H., (1933). A bibliographical monograph on plant genetics 1900-1929 (Genic analysis). Sapparo, Japan.

Matusima, K., (1936). Chromosome doubling in the rice plants treated with high temperature. *Pl. Breed.* **6**, *Abs.* No. 565.

McCarrison, R., (1928). The influence of irrigation on the nutritive value of rice. *Ind. J. Med. Res.* **15**, 15-20.

McCollum and Simmonds, N. (1917). A biological analysis of pellagra producing diets. III. The value of some seed proteins for maintenance. *J. Biol. Chem.* **32**, 347-68.

McKerral, (1913). Some features of rice improvement in Lower Burma. *Agric. J. India* 8, 317-30.

Mc Rae, W., (1918). Blast of paddy in Tanjore District. *Mad as Agric. J.* **6**, **115-21**.

Mendiola, N.B., (1920). An inhibitor in rice. *Jap. J. Bot.* 3, *Abs.* No. 2170.

—— (1922) The study of the inheritance of beard dness of rice in natural **hybrids.** ***Phil. Agric. Rev.*** . **5, 28-43.**

—— (1926). A manual of plant breeding in the tropics. *Univ. Phil.* Manila.

Mitra, S.K., (1924). Seasonal variation in paddy. *Agric. J. Ind.* 91, 590-9.

—— (1933). Rice breeding in Assam. *Proc. World's Grain Exh. and Conf. Regina* **2**, 131-3.

and Ganguli, P.M., (1932). Some observations on the characters of wild rice hybrids. *Indian J. Agric. Sci.* **2**, **271-9**.

—— (1932). Studies in Surma valley rices and their classification. *Indian J. Agric. Sci.* **2**, **571-607**.

—— (1934). Inheritance of albino and white-striped seedlings in rice. *Indian J. Agric. Sci.* **4**, **537-45**.

—— (1937). Inheritance of inner glume colours in rice. *Indian J. Agric. Sci.* **7**, 126-34.

—— (1938). Inheritance of size and shape of grain in rice. *Proc. 25th Ind. Sci.* ***Con-Abs.*** 13.

— Ganguli, P.M. and Gupta, S N. (1928). Colour inheritance in rice. ***Mem.*** *Dept. Agric Ind Bot. Ser.* 15, **85-102.**

Miyazawa, B., (1932). On two cases of semi-sterility in *Oryza sativa*, *Jap J. Bot.* **6**, *Abs.* **148.**

—— (1935) Studies on mutations in rice. *Bull. Miyazawa Coll. Agric.* **7**, 1-110. (Japanese with English summary).

Morinaga, S., (1927). On the chlorophyll deficiency that appeared in rice. (Jap.) *Bot. Mag. Tokyo* **41**, 571-6.

—— T. (1932). The chlorophyll deficiency in rice. *Bot. Mag., Tokyo* **46**, 202-6.

—— (1934). Some observations on *Oryza minuta*. Presl. (Japanese) *Pl. Breed.* **5**, *Abs.* No. 715.

—— (1935). Cytogenetical studies in *Oryza sativa*. II. Autotriploid mutants. Spontaneous, *Jap. J. Bot.* **7**, 207-25.

—— (1938). Inheritance in rice, *0. Sativa L.* II. Linkage between the gene for purple plant colour and the gene for liguleless. *Jap. J. Bot.* **9**, 121-9.

—— (1940). The size and form of caryopses and their mode of inheritance. *Pl. Breed. Abs.* 10, No. 148.

—— (1940). Cytological studies. *Biol. Abs.* **16**, No. 3582.

—— and Aoki, M., (1938,(a). On the microsporogenesis of various interspecific rice hybrids in *Orzya Pl. Breed, Abs.* 8, No. 1204.

—— and Fukushima, E., (1932). Preliminary report on the haploid plant of rice, *Oryza sativa* L. *Proc. Imp. Acad.* **7**, 383-4. **8**, 403-5.

—— (1934). Cytological studies on *Oryza sativa* L. I. Studies on the haploid plant of *O. sativa*. *Jap. J.Bot.* **7**, 73-106.

—— Fukushima, M. (1936). Cytogenetical studiefs in *Oryza sativa* III. Spontaneous, auto-tetraploid mutants in *Oryza sativa*. *Jap. J. Bot.* **9**, 71-94.

Morita, K. (1938). Studies in the sterile rice plant. *Pl. Breed. Abs.* **9**, No. 275.

Mukerjee, J.A. (1933). *Ann. Report Rice Research Scheme.* Raipur, Central Provinces, 1932-33.

Mukhin, N.D., (1942). Variability in the yielding capacity of the seed from different parts of t ear. *Pl. Breed. Abs.* **12**, No. 982.

Mulimbayan, M.B., (1935). A comparative study of two methods emascultiang rice flower for artificial hybridisation *Phil. Agric.* **24**, 574-90.

Muller, H.J., (1930). Are progressive mutations produced by X-rays ? *Genetics.* **15**, 495-577.

Mundkur, B.·B, (1935)· Parasitism of *Sclerotium oryzae* catt. *Indian J. Agric. Sci.* **5**, 393-415.

Nagai, I., (1910). Quoted by Ramiah and Mudaliar (1937).

—— (1916). Some studies on the germination of seed of 6. *Sativa*. *J. Coll. Agric. Imp. Univ.* Tokyo, **3**, 109-58.

—— (1921). A Genetico-physiological study on the formation of anthocyan and brown pigments in plants. *Jap. J. Bot.* **1**, *Abs.* 64.

—— (1926). Studies on the mutations in *Oryza sativa*, I, II, III, and IV. *Jap. J. Bot.* **3**, 25-96.

——and Imamira, (1931). Morphology of the neck of panicle as related to the resistance against blast disease in rice varieties. *Pl. Breed. Abs.* **2**, No. 355.

Nagao, K. and Takaro, T, (1938). Duration of preservation and fertilisation possibilities in pollen and stigma of rice plant. *Jap. J. Bot.* **9**, *Abs.* 559.

Nakamori, (1932). On the appearance triploid plant of rice, *Oryza sativa*. *Jap. J.Bot. of* 6, *Abs.* No. 282.

—— (1933). On the occurrence of tetraploid plant of rice, *Oryza sativa*. *Jap. J. Bot.* **7**, *Abs.* No. 66.

Nakatomi, S., (1926). On the variability and inheritance of the resistance of the rice plant against the rice blast disease. *Jap. J. Bot.* **3**, *Abs.* 297.

Nakayama, K., (1935). On the inheritance of anthocyan formation in various organs of rice plant *Biol. Abs.* **11**, No. 2652.

—— (1939). Dwarf types of rice. *Pl. Breed. Abs.*10, Nos. 449 and 1045.

(1942). Comparative development of panicles in normal and dwarf types of rice plant. *Pl. Breed. Abs.* **12**, No. 164.

Namaguti, F., (1933). Correlation between ear density, size and uniformity of kernels. *Bull. Miyazawa Coll. Agric.* **5**, 13.

Nandi, H.K., (1936, b). The chromosome morphology, secondary association and origin of cultivated rice, *J. Genet*, **33**, 315-36.

—— (1937). Cytological Investigations of rice varieties. *Cytologia* (Tokyo) 8, 277, 305.

—— (1937). Effect of temperature on the formation of diploid pollen grain in *Oryza sativa* L. *Abs. Pro. 24, Ind. Sci. Cong.* 268.

—— (1938). Interspecific hybridisation in *Orysa.* Cytogenetical evidence of the hybrid origin of *Oryza minuta. Bose Res. Inst. Trans.* Calcutta (1935-36) 99-121.

—— and Ganguli, P.M. (1940). Inheritance of the colour of lemma and palea in rice, II. *Proc. 27th Ind. Sci. Cong. Abs.* 32.

—— (1941). Inheritance of earliness in Surma valley rices. *Indian. J. Agric. Sci.* 11, 9, 20.

—— (1941). Inheritance of height of plants in *sail* paddy. *Proc. 29th Ind. Sci. Cong. Abs.* **34**, (Agriculture).

Narasingarao, M.B.V. (1937). A note on a few experimental observations in the Rice Research Station Berhampur (Madras). *Indian J. Agric. Sci.* **7**, 733-4.

Noguchi, Y., (1929, a). Studies on the influence of external conditions on the flowering of rice plants. *Jap. J. Bot.* **4**, **5**, 237-76.

—— (1929, b). Longevity of pistil and pollen in rice. *Biol. Abs.* **3**, No. 8898.

—— (1929, d). On control of flowering time by action of light. *Jap. J. Bot.* **4**, *Abs.* **52** and *Jap. J. Bot.* **5**, *Abs.* 238.

—— (1931). Pollen germination in rice. *Jap. J. Bot.* **5**, 351-69.

—— (1942). Photoperiodism and vernalisation. *Pl. Breed. Abs.* **2**, No. 99.

Nomura, M. and Yamazaki, R. (1927). A study of the inheritance of shooting time in the rice plant. *Jap. J. Bot.* 3, *Abs.* 357.

Okura, E., (1937). Cytogenetical studies in *Oryza* ; a preliminary note on the interspecific hybrid between *O. sativa* and *O. minuta. Jap. J. Genet.* 13, 212-4.

Onodera, J., (1930). Variability and development of mechanical tissue in leaves of rice plants and its correlation in drought resistance. *Jap. J. Bot.* **5**, *Abs.* 61.

—— (1933). Studies on drought resistance ; morphological and physiological modification and variation of yields for different soil moisture contents in rice plant. *Jap. J. Bot.* **6**, *Abs.* 53.

Oryoshi, G., (1936). Mutations induced by X-rays *J. Taihoku Soc. Agric. and Forestry* 1, No. 3.

Ossewarde I-J.D., (1934). Vernalisation of rice *Pl. Breed. Abs.* **5**, *No.* 26.

Padmanabhan, S.Y. Roy Choudhury, K.R. and Ganguly. D. (1948). *Helminthosporium* disease of Rice, *Ind. Phyto. I,* 1, 34-47.

Page, R.M., Sherf,, A.F. and Morgan, T.L. (1947). The effect of temperature and relative humidity on the longevity of conidia of *H. Oryzae. Mycologia* **39**, 2, 158-64.

Pal, B.P. and Ramanujam. S. (1941). A new type of variegation in rice. *Ind. Jour. Agri. Sci.* **11**, 170-6.

Pan, C.L., (1935). Uniformity trials with rice. *J. Amer. Soc. Agrom.* **27**, 279-85.

—— (1936). Length of exposure to light and plant growth. *J. Amer, Soc. Agron.* **28**, 58-63.

—— (1936). A preliminary report of varietal differences in rapidity of germination in rice. *J. Amer. Soc. Agron*, **28**, 985-9.

Panse, V.G., (1940). *Proc. 2nd Conf. of Cotton Workers in India.* **2.**

—— (1942). Studies in technique of field experiments. Size and shape of plots in cotton trials. *Indian J. Agric. Sci.* 11, 850-65

Parija, P., (1938), (1940), (1941). *Ann. Report, Rice Res. Scheme, Orissa*, 1939-40 and 1940-41.

— (1943). On the seed treatment and phasic development. *Curr. Sci.* 12, 88-9.

Parnell, F.R., (1921). Note on the detection of segregation by examination of the pollen of rice *J. Genet.* 11, 209-12.

—— Rangaswamy Ayyengar, G.N. and Ramiah K., (1917). Inheritance of characters in Rice. I. *Mem. Dept. Agric. Ind. Bot. Ser.* 9, 75-105.

—— Rangaswamy Ayyengar, G.N., Ramiah, K. and Ayyangar, C.R.S. (1922). The inheritance of characters in rice. II. *Mem. Dept. Agric. Ind. Bot. Ser.* 11, 185-208.

Parthasarathy, N., (1927). Blooming of rice and development of grain *Mad. Agric. J.* 15. 173-7.

—— (1935). The inheritance of multiple pistils in rice. *Pro. Assoc. Econ. Biologists, Coimbatore* 3. 32-41.

—— (1938). Cytogenetical studies in *Oryzae and Phalarideae*. I. Cytogenetics of some X-ray derivatives in rice. *J. Genet*; 37, 1-40.

—— (1938). Cytogenetical sudies in *Oryzae* and *Phalarideae*. II. Further studies in *Oryza*, *Cytologia* (Tokyo) 9, 307-18.

—— (1939). Cytogenetical studies in *Oryzae* and *Phalarideae*. III. Cytological studies in *Phalarideae*. *Ann. Bot.* 3. 43-76.

—— (1942). An Indian source of Colchicine. *Pl. Breed Abs.* 12. No. 310.

Parthasarathy, S.V. (1940). Physiological studies during vernalisation in rice. *Mad. Agric. J.* 28, 133-7.

Percival, C., (1921). The wheat plant. 425.

Phatak, G.N., (1940). Studies in the cytology of cereals. *J. Genet.* 89, 437-67.

Piacco, R., (1937, b). The secondary awning in rice. *Pl. Breed. Abs.* 7, No. 1268.

—— (1939, a) The genetical behaviour of a mutation of *Oryza sativa*. *Pl. Breed. Abs.* 9, No. 1493.

—— (1939, b) Phenotypes obtained from cross Nanox Nanetto. *Pl. Breed. Abs.* 9. No. 1491.

Poggendorff, W., (1932) *Report of Plant Breeding achievements in New South Wales.*

—— (1933). Artificial hybridisation of rice. *Agric. Gaz.* N. S. Wales, 44, 283-8.

Rajasekhara Mudaliar, C.—(1936). A note on the formation of starch in the developing rice kernel. *Proc. Asso. Economic Biologists* (Coimbatore) 4, 53-7.

Ramakrishna Ayyar, T.V. (1940). Hand-book of economic entomology for South India.

Ramanujam, S. (1935). Male sterility in rice. *Mad. Agric. J.* 23, 190.

—— (1937, a). Cytogenetical studies in *Oryzae*, II. Cytological behaviour of an autotriploid in rice. *J. Genet.* 35, 223-58.

—— (1937, b). Cytogenetical studies in the *Oryzae*, III. Cytogenetical behaviour of an interspecific hybrid in *Oryza*. *J. Genet.* 35, 223-58.

—— (1938). Cytogenetical studies in *Oryzae*. I. Chromosome studies in the *Oryzae* *Ann. Bot. N.S.* 2, 107-26.

—— and Joshi, A.B. (1941). Colchicine induced polyploidy in crop plants. I. Gram (*Cicer arietinum*). *Indian J. Agric. Sci.* 11, 835-49.

—— and Parthasarathy, N. (1935). An asynaptic mutant in rice. (*Oryza sativa*). *Proc. Ind. Acad. Sci.* 2, 80-7.

Ramaswamy, K. (1933). The period of receptivity of rice stigma. *Mad. Agric. J.* 21, 514-9.

—— (1935). The relation between the size of seed and the development of the plant resulting from it in rice. *Mad. Agric. J.* 23, 240.

Ramiah, K. (1924). Some experiences in the laying out of comparative trial plots in rice breeding. *Mad. Agric. Dept.* Year Book 1925, 36.

Ramiah, K. (1926). Some observations on the flowering phase of the wild species of *Oryza Mad. Agric. Dept. Year Book* 1925-26.

—— (1927). Artificial hybridisation in rice. *Agric. J. Ind.* **22**, 17-23.

—— (1927, b). A note on growth phases of paddy varieties. *Madras Agric. J.* **15**, 40-9.

—— (1930). The inheritance of characters in rice. Part III. *Mem. Dept. Agric. Ind. Bot. Ser.* **18**, 211-7.

—— (1931). Preliminary investigations on the occurrence of sterility in rice. *Agric. and Livestock in India.* **1**, 414-26.

—— (1931), (1932) and (1935). *Mad. Agric. Stn. Reports, Paddy Breed. Stn. for 1930-31 to 1935-36.*

—— (1932). Use of Smear Technique for chromosome counts in Rice. *Curr. Sci.* **1**, **166**.

—— (1933, a). Inheritance of flowering duration. *Indian J. Agric. Sci.* **3**, 377-410.

—— (1933, b). Inheritance of height of plant in rice. *Ind. J. Agric. Sci.* **3**, 411-32.

—— (1933, c). Inhibitory factor hypothesis and the inheritance of flowering duration and plant height in rice. *Indian J. Agric. Sci.* **3**,446-56.

—— (1933, d). Genetic association between flowering duration and plant height and their relationship to other characters in rice. *Indian J. Agric. Sci.* **3**, 433-45.

—— (1935). Rice Genetics. *Proc. Assocn. Econ. Biologists*, Coimbatore **3**, 51-61.

—— (1936). Thickness of bran layers in rice. *Curr. Sci.* **5**, 215.

—— (1937, a). Scent in rice. *Mad. Agric. J.* **25**, 173-6.

—— (1941). Plant breeding and genetical work in India. *Presidential Address, Agric. Sec. 28th Ind. Sci. Cong.*

—— (1945). Anthocyan in genetics of cotton and rice. *ndian J. Genet. and Pl. Breed.* **5**, 1-14.

—— and Hanumantharao, K. (1936) Inheritance of grain shattering in rice. *Mad. Agric. J.* **24**, 240-4.

—— and Mudaliar, S.D. (1934). Lodging of straw and its inheritance in rice. (*Oryza sativa*). *Indian J. Agric. Sci.* **4**, 880-94.

—— and Narasimham, M. (1936). Developmental studies in rice. *Mad. Agric. J.* **24**, 50-66.

—— and Parthasarathy, N. (1933). Inheritance of grain length in rice (*Oryza sativa* L.) *Indian J. Agric. Sci.* **3**, 808-19.

—— (1936). An ageotropic mutation in X-rayed rice. *Curr. Sci.* **5**, 135-6.

—— (1938). X-ray mutations in rice. *Proc. 25th Ind. Sci. Cong. Abs.* **12**.

—— and Ramanujam, S. (1935). Chlorophyll deficiency in rice. *Proc. Ind. Acad, Sci.* **2**, 343-68.

—— and Ramaswamy, K. (1936). Breeding of resistance to *Piricularia oryzae* in rice. *Proc. Ind. Acad. Sci.* **3**, 450-9.

—— (1941, a). Floating habit in rice. *Indian J. Agric. Sci.* 11, 1-8.

—— (1941, b). Hybrid vigour in rice (*Oryza sativa* L.) *Ind. J. Genet. and Plant Breed.* **1**, 4-12.

—— and Mudaliar, C.R. 1935 The inheritance of red pericarp colour in rice. *Mad. Agric. J.* **23**, 268-9.

—— and Rajasekhara Mudaliar, C. (1937). Colours in the rice grain. *Indian J. Agric. Sci.* **7**, 863-72.

—— (1939). Proteins in the rice grains and the development of aleurone layer. *Indian J. Agric. Sci.* **9**, 39-53.

—— Jobithraj, S. and Mudaliar, S. D.(1931). Inheritance of characters in rice. Part IV. *Mem. Dept. Agric. Ind. Bot. Ser.* **18**, 229-59.

—— Parthasarathy, N. and Ramanujam, S. (1932). Haploid plants in rice. *Curr. Sci.* **1**, 277.

—— (1933). Triploid mutation in rice. *Curr. Sci.* **2**, 170-2.

—— (1934, b). A haploid plant in rice. *J. Ind. Bot. Soc.* **13**, 153-64.

—— (1935, a). Tetraploid plant in wild rice. *Proc. Ind. Acad. Sci.* **1**, 566-70.

Ramiah, K. Parthasarathy N. and Ramanujam S. (1935, b). Polyembryony in rice. *Indian J. agric. Sci.* **5,** 119-24.

Rau. N. S. (1929). Further contributions to the cytology of some crop plants of South India. *J. Ind. Bot. Soc.* **8**, 201-6.

Reyes, G. M. (1937). Disease resistant hybrids produce more yields in commercial trials. *Phil. J. Agric.* **8, 417-23.**

Reyes, G. A. and others (1933). Observations of two forms of sterility in rice. *Phil. J. Agric.* **16,** 46-8.

Riker, A. T. and Riker. R. S. (1936). Introduction to research on plant diseases. *Univ. Wisconsin Publication.*

Rhind, D. (1931), (1937). *Ann. Rep. Econ. Bot.* Burma, 1930-31 and 1936-37.

Rjabov, I. E. (1942). Rice breeding according to the theory of phasic development of plants. *Pl. Breed. Abs.* **12**, No. 1082.

Rodrigo, P. A. (1925. b). A case of polyembryony in rice. Phil. *Agrst.* **14**, 629-30.

Roschevicz, R. J. (1931). A contribution to the knowledge of rice. *Bull. of Applied Botany. Genetics and Pl. Breed.* **27**, No. 4, 1-133.

Roxoborough (1932). **Flora Indica 2, 200.**

Roy, S. C. (1921). A preliminary classification of wild rices of the Central Provinces and Berar. *Agric. J. Ind.* **16**, 365-80.

Ryker, T.C. and Chilton, S. W. (1940). Three physiological forms in Cercospora. *Pl. Breed. Abs.* **10**, No. 455.

Ryker, T. C. and Chilton. S.J.P. (1942). Inheritance and linkage of factors for resistance to two physiologic races of *Cercospora Oryzae* in Rice. *J. Amer. Soc. Agron.* **34,** 836-40.

Sadasivan, V. and Srinivasan, A. (1938). Studies on quality in rices, II. Chemical composition of rice varieties. *Indian J. Agric. Sci.* **8,** 807-18.

Sakai, K. (1935). Chromosome study in *Oryza sativa* L. I. The secondary association of the meiotic chromosomes. *Pl. Breed. Abs.* **6**, No. 564.

—— (1935). Studies on the effect of x-rays radiation upon the germination, growth and yield of rice plants. *Jap. J. Bot.* **8**, *Abs.* 454.

Sakai, H. (1939). Interfering effects of temperature upon the microsporogenetic cell division in rice plant. *Pl. Breed. Abs.* **9**, No. 752.

—— (1939). Preliminary note on the nucleoins and nucleolar chromosomes in *Oryza sativa* L. *Pl. Breed. Abs.* **10**. No. 451.

Sampath, S. and Krishnaswamy, V. (1948). A chromosome deficient paddy type. *Curr. Sci.* **17**, 271-2.

Sampietro, G. (1937). **Mutation in rice.** *Pl. Breed. Abs.* **7**, No. 1266.

Sands, W. (1929). Selecting high yielding varieties of rice in Malaya. *Proc. Imp. Bot. Conf.* 93.

Sarangapani, G. (1924). A few observations on paddy crossing. *Agri. Jour. Ind.* **19, 48-51.**

Sarvayya, C. V. (1932). Physiology of tillering in paddy. *Mad. Agri J.* **20**, 179-91.

Sasaki, N. E. (1922). Inheritance of resistance to *Piricularia oryzae* in different varieties of rice. *Jap. J. Bot.* **1**, *Abs.* 112.

Sax, K. (1937). The experimental production of poly ploidy. *Pl. Breed. Abs.* **7**, No. 539.

—— (1938). Ditto. *Pl. Breed, Abs.***8**, No. 410.

Selim. A. G. (1930). A cytological study of *Oryza sativa* L. *Cytologia* (Tokyo) **2**, 1-26.

Sethi, B. L. (1937). Cytological studies in paddy varieties. *Indian J. Agric. Sci.* **7**, 687-706.

Sethi, R. L. (1930). Root development of rice under different conditions of growth. *Mem. Dept. Agric. Ind. Bot. Ser.* **18**, 57-80.

—— (1933), (1934), (1935) (1936), (1937), (1938) (1939) and (1940). *Ann. Repts. of the Rice Res. Stn. Nagina. United Provinces,* 1932-33, 1933-34, 1934-35, 1935-36. 1937-38, 1939-40.

—— and Saxena. B.P. (1930). Classification and study of characters of cultivated rices in the United Provinces. *Mem. Dept. Agric. Ind. Bot. Ser.* **18**, 149-210.

——Sethi, B.L. and Mehta, T. R. (1936,a). Earliness in United Provinces rices. *Indian Agric. Sci.* **6, 361-75.**

Sethi, R.L., Sethi, B.L. and Mehta, T.R. (1936, b).	Inheritance of earliness in United Provinces rices. I. *Indian J. Agric. Sci* 6, 1246-74.
—— (1937, a).	Inheritance of the sheathed ear in rice. *Indian J. Agric. Sci.* 7, 134-49.
—— Sethi, B. L. and Mehta, T.R. (1937, b).	Awnedness and its inheritance. *Ind. J. Agric. Sci.* 7, 589-600.
—— Sethi, B. L. and Mehta, T. R. (1938).	Inheritance of earliness in United Provinces rices, II. *Indian J. Agric. Sci.* 8, 1-20.
Shaw, F.J.F. (1913)	A sclerotial disease of rice. *Mem. Dept. Agric. Ind. Bot. Ser.* 6, 11-23.
Shen, H. N. (1938).	A study of polygynous rice. *Pl. Breed. Abs.* 7, No. 689.
Sherf, A.F., Page, R.M., Tullis, E.C. and Morgan, T.L. (1947).	Studies on factors affecting the infectivity of *H. oryzae*. *Phytopath.* 37, 281-90.
Silow, R.A. (1939).	Genetics of leaf shape in diploid cottons and the theory of gene interpretation. *J. Genet.* 38, 229-97.
Singh, B.N. (1940).	Agricultural and Animal Husbandry in India, 1939-40.
Sircar, S. M. (1942).	Photoperiodism in rice. *J. Ind. Bot. Soc.* 21, 41-50.
Sircar, S. M. (1948).	Vernalisation and Photoperiodism in the tropics: Vernalisation and photoperiodism. A Symposium, Chronica Botanica, 121-8.
Skazin, F.D. (1936).	Osmotic pressure of the seed as a criterion of the drought resistance of plants. *Pl. Breed. Abs.* 6, No. 124.
Skripcinskii, V. (1940)	*Trop. Agrst.* 95, 205-11.
Smith, F.H. (1936).	A discriminant function for plant selections. *Ann. Eng.* 7, 240-50.
Smits, M.B. (1931).	Factors influencing root development in rice and some consequences. *Int. Rev. Sci. and Pract. Agri. Rome* 22, 169-79.
Srinivasan, A. (1937).	Progress report of biochemical investigations in rice. I.C.A.R. publication, New Delhi.
—— (1938, a).	Studies on quality in rice. IV, Storage changes in rice after harvest. *Indian J. Agric. Sci.* 9, 208-22.
—— (1939, b).	Availability of phosphorous in rice. *Nature* 143, 244.
—— (1942).	Nutritive values of the proteins and mineral constituents of rice varieties' *Cereal Chemistry*, 19, 36-47.
—— (1946).	Nutritional improvements of rice. *Curr. Sci.* 15, 180-3.
—— and Sadasivan, V. (1942).	Nutritive value of the proteins and mineral constituents of dry and wet cultivated rices. *Cereal Chemistry* 19, 47-55.
—— and Venkatagiri, K. (1939).	Studies on quality in rice, III. In vitro digestibility of different varieties of rice. *Indian J. Agric. Sci.* 9, 193-207.
Srinivasan, C.R. (1926), (1928), (1929), (1930), (1937), (1938), 1939), (1940) and (1941).	*Madras Agric. Stn. Reports* for 1925-26, 1927-28, 1928-29, 1929-30, 1936-37, 1937-38, 1938-39, 1939-40 and 1940-41.
Srinivasa Ayyangar, C. R. and Ramiah, K., (1933).	The problem of lodging in rice crop in the Godavary delta. *Abs. Proc. Assoc. Econo. Biologists, Coimbatore, S. India* 1, 40.
Srinivasan, C. R., Parthasarathy, N. and Ramaswamy, K., (1941).	Interspecific hybridisation. *Proc. 28th Ind. Sci. Cong. Abs. 38*, (Agri. Section).
Stadler, J., (1924).	An experimental study of the varicities as an agronomic unit in wheat and oats. *J. Amer. Soc. Agron.* 16, 366-72.
Stevens, N. E. (1933).	Suggestion for a Pan-Pacific survey of rice diseases. *Proc. 5th Pac. Sci-Cong.* 4, 3239.
Stewart A. B, (1947).	Report on Soil fertility investigations in India with special reference to manuring.

Subrahmanyan, V., Srinivasan, A. and Das Gupta H. P., (1938), Studies on quality in rice, I. Effect of milling on the chemical composition and commercial qualities of raw and parboiled rices. *Ind. J. Agric. Sci.* 8, 459-86.

Suji, H. and Kitagawa, Y., (1926). An example of the independent inheritance of the colour of awns and glume tips. *Biol. Abs.* 2, No. 156.

Sugimoto, S., (1923). Some examples of production of the anomalous races in rice. *Biol. Abs.* 14, No. 810-1.

Sundararaman, S., (1922). *Helminthosporium* diseases *of Rice. Agric. Res. Inst. Res. Bull. 12z.*

Suzaki, H., (1934). Studies on the influence of some environmental factors on the rice plant to blast and *helminthosporium* diseases and on the anatomical characters of the plant. *Coll. Agric. Imp. Univ.* Tokyo, 13, 45-108, 235-331.

—— (1935). On the physiologic specialisation of *Piricularia oryzae in* Corea. *Jap. J. Bot.* 7, No. 196.

Susrutha., (1938). '*Sarira*' (Telugu translation from Sanskrit).

Tabata, K., Wogata, K. and Shirakawa, M., (1932). On the effect of day length upon emergence of panicle in rice. ***Pl. Breed.*** *Abs.* 3, No. 228.

Takahashi, N., (1923). An example of factor linkage in rice. *Jap. J. Bot.* 2, No. 111.

—— (1935). Further observations on the linkage relation between the factors of endosperm characters and the colour of awns in rice plant. *Biol. Abs.* 11, No. 5333.

—— (1937). Studies on the linkage relations between the factors for endosperm characters and sterility in rice with special reference to selective fertilisation. *Pl. Breed. Abs.* 8, No. 1547.

—— (1939). Linkage relation between factors for endosperm and colour of awn in rice *Jap. J. Genet.* 10, 200-9.

Takezaki, Y., (1921). Inheritance of leaf colour in purple rice. *Jap. Jour. Genet.* 1, 37-43.

—— (1923). Inheritance of purple leaf colour in rice plants, II. *Imp. Jour. Genet.* 2, 95-101.

—— (1932). Inheritance of some lax panicles in rice. *Pl. Breed. Abs.* 3, No. 82.

Tanaka, T., (1941). A method of rendering difficult interspecific crossing successful by means of X-rays. *Pl. Breed. Abs.* 11, No. 663.

Tang, W. G., (1937). Mode of inheritance of length of spikelet in rice. *Pl. Breed. Abs.* 7, No. 668.

Taylor, J. W., (1928). Effect of continuous selection of large and small wheat seed on yield. *J. Amer. Soc. Agron.* 20, 856-67.

Takenouchi, Y., (1924). Studies on seed abscission in rice plants in Formosa. *Jap. J. Bot.* 2, Abs. 184.

Terada, S., (1928). Embroylogical studies in *Oryza sativa* L. *Jap. J. Bot.* 4, *Abs.* No. 233.

Terao, H., (1917). On reversible transformibility of allelomorphs. ***Amev. Nat.*** 51, 690-8.

—— (1921). Mutation and inheritance of semi-sterility in rice plant. *Jap. J. Genet- Bot.* 1, *Abs.* No. 35.

—— (1921). Brown colour of rice grain. *Int. Rev. Sci. Proc. Agric.* 2, 15.

—— (1930). The present state of rice. Improvement of rice in Japan. *Proc. 3rd Pan Pacific Cong.* 2, 1179-85.

—— *et al* (1939). Some considerations on classification of rices into so-called *Japonica* and *Indica. Pl Breed. Abs.* 10, Nos. 150 and 151.

—— and S. Kato., (1922). Mutation of large grained rice specially regarding the frequency of allelomorphic transformation. *Jap. J. Genet.* 1, 127-57.

Thadani, K. I. and Durgadatta, H., (1928). Studies on rice in Sind. Part 1. *Mem. Dept. Agric. Ind. Bot. Ser.* 15, 113-59.

Thomas, K. M., (1930). Some aspects of the control of blast disease of paddy. *Mad. Agric. J.* 18, 596-605.

—— (1931). A new paddy disease in Madras. *Mad. Agric. J.* 19, 34-6.

—— (1933). The foot rost of paddy and its control. *Mad. Agric. J.* 21, 263-72.

Thompstone, E., (1915). Some observations on Upper Burma paddy. *Agric. J. Ind.* 10, 26-53.

Timofeef, R., (1950). *The New Systematics.*

Tin, M. (1936). Developmental variation in the paddy grain. *Indian J. agric. Sci.* 6, 396-459.

Ting, Y., (1933). Wild rice hybrids. *Pl. Breed. Abs.* 5, No. 378.

Tippet, H., (1931). *Elements of statistics.*

Titta, G., (1934). On a mixture of five varieties of wheat. *Pl. Breed. Abs.* 4, No. 133.

Torrens, J. P., (1930). Some experiences in rice hybridisation. *Phil. Agric. Rev.* 20, 261-4.

Tullis, E. C., (1940). Rice leaves infected with *Helminthosporium oryzae*. *J. Agric. Res.* 50, 81-90.

—— and Cralley, R. M., (1933). Laboratory and field methods on the development and control of stem rot of rice. *Arkansas Agric. Exp. Sta. Bull.* 295.

—— Wood, J.B. and Caster, D. G., (1933). Control of stem rot of rice by burning stubble, *Agric. Eng.* 14.

Unite, J. O., (1920). Comparative tests of rice seeds from principal and poorest culms in individual plants. *Phil. Agrst.* 10, 243-52.

Van der Stok, J. E., (1908). On the inheritance of grain colour in rice. *Teysamannia*, 65 : 5.

Vavilov, N. I. (1928). *The law of homologous series in hereditary variations.*

—— (1930). The problems of the origin of cultivated plants and domestic animals, as conceived at the present time. *Pl. Breed. Abs.*

—— (1940). *The New Systematics.*

Venkataraman, S. N. and Subramanian, P., (1938). Biometric studies in sorghum. *Indian J. Agric. Sci.* 8, 609-25.

Vibar, T. N., (1920). Variation and correlation of characters among rice varieties. *Abs. in Int. Prc. Sci. and Pr. Agric.* 13, 182-4.

Viellard, (1921). Improvement of rice by hybridisation in Java. *Trop. Agrst.* 57, 232.

Watt, G., (1892). Dictionary of Economic products, 5, 498-654.

Webber, J. W. (1940). Polyembrony *Bot. Rev* 6 : 575.

Winton, (1937). Quoted by Ramiah and Mudaliar (1937).

Yamaguchi, Y., (1938). A preliminary note on the inhibitory factor for leaf colouration. *Pl. Breed. Abs.* 8, No. 115.

Yamaguti, Y., (1918). Contribution to the knowledge of xenia in *Oryza sativa* (Jap.), *Bot. Mag.* 32, 89-90.

—— (1921). Hereditary studies on the colour of glumes of rice and a case of repulsion between a gene for colour and for endosperm character. *Int. Rev. Sci. and Prac. Agric.* 12, 1399-1401.

—— (1926). Genetical analysis of the awn, glume colour and existence of endosperm in some varieties of rice. *Ber. Chara Inst. Landw. Fosch.* 3, 1-126.

—— (1927). Linkage studies in rice. *Ber. Chara Inst. Landw. Fosch.* 3, 319-30.

—— (1927, b). Quoted by Matsuura 1933.

—— (1929, a). Genetical studies in rice ; Further contributions to the knowledge of the second (S-M) linkage group in rice. *Jap. J. Bot.* 5, Abs. No. 86.

—— (1929, b). Genetical studies in rice. *Jap. J. Bot.* 5, *Abs.* 87.

—— (1932). Crossing investigation on rice plants, III. Genetics of colour characters of various parts of the plant. *Pl. Breed. Abs.* 2, No. 448.

Yamasaki, M., (1928). Study on the abscission of spikelet in *Oryza sativa*. *Jap. J. Bot.* 4, Abs. 357.

—— (1929). Determination of drought resistance of rice varieties by means of their seed germination in various solutions. *Jap. J. Bot.* 4, *Abs.* No. 352.

Yamura, A., (1933). Quoted by Nandi (1936, b).

Yates, F. and Cochran, 1938). Analysis of groups of experiments. *J. Agric. Sci.* 28, 556-80.

Yoshika, T. and others, (1936). Studies on the physiological specialisation in *Piricularia Oryzae*. *Jap. J. Bot* 6, No. 193.

Yoshi, Y., (1927). Some preliminary studies on the influence of rice plants of relative length of day. *Jap. J. Bot.* 3, *Abs.* No. 209.

APPENDICES

APPEN

1. BEN

DESCRIPTION OF

(a) *Agricultural Research*

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
Kataktas ..	Dacca 2	S. P. S.	Autumn	April to May	July to August	100	Dark purple	Gold
Panbira ..	.. 12	..	..	..	..	100	Green	Straw
Pusur	.. 18	Hybrid	..	..	..	90	Light purple	Reddish brown
Pukhi	.. 8	T. S.	..	..	..	90	..	Gold
Kumari .	.. 16	..	..	..	..	100	Green	Straw
Dharial ..	.. 14	..	..	..	..	95	..	..
Marichabati ..	.. 24	..	..	..	..	90	Light Dy. furrows	Brown
Atlai	.. 10	..	..	..	..	100	..	Gold
Charnock ..	.. 6	..	..	..	..	100	..	Straw
Dular	.. 22	Hybrid	..	..	..	85	Gold	Reddish brown
Surjamukhi ..	.. 4	S. P. S.	..	..	..	100	..	..
Paspai	.. 20	P. S.	..	..	..	95	Green	Straw
Dudsar	.. 5	..	Winter	June to July	November to December	165	..	..
Jhinga sail ..	.. 15	..	..	..	..	165	Gold	Light Gold
Nigersail ..	.. 25	..	..	..	..	165	Green	Straw
Blue stick .	.. 19	American	..	..	..	165	..	..

DIX I

GAL

IMPROVED VARIETIES

Station, Dacca

Awn	Size of paddy			Colour	Texture	Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)							
nil	9·1	2·5	1·9	White	Transl.	..	..	..	2300	Medium fine, suitable for eastern and northern Bengal
,,	7·6	3·1	2·1	Light red	Abd. white	..	..	..	2600	Coarse grained late
,,	8·8	2·9	2·0	,,	,,	..	..	..	2650	Early, suitable for double cropped land
,,	8·4	2·9	2·1	Red	,,	..	..	..	1850	Medium grained, early, suitable for double cropped land
,,	8·9	2·5	1·9	White	Transl. Abd.	..	..	..	2950	Medium fine suitable for high land
,,	7·9	3·6	2·3	Red	White	..	..	..	2550	Coarse grained, may be grown broadcast or transplanted.
,,	8·6	3·7	2·3	,,	Abd. white	..	..	..	2550	Coarse grained, early
,,	9·3	2·5	2·0	Light red	,,	..	..	..	2600	Late, suitable for lower situations
,,	9·4	2·1	1·8	White	Transl.	..	..	..	1700	Finest among *aus* paddies
,,	8·8	2·8	2·1	Very light red	Abd. white	..	..	..	2100	Medium grained, early
,,	8·9	2·5	1·9	Light gold	,,	..	..	..	2650	Medium-fine, suitable for eastern and northern Bengal
,,	8·6	3·3	2·3	Red	,,	..	..	..	1700	Early, cultivated in Central Bengal
Awn	10·3	2·7	2·1	White	,,	..	..	..	2950	Drought-resistant
,,	11·2	2·4	2·0	,,	,,	..	..	..	2700	Drought-resistant suitable for puffed and beaten rice
nil	8·3	2·5	1·8	,,	Transl.	..	..	..	2500	Hard, medium-grained, rice
,,	9·8	2·7	2·0	,,	,,	..	..	..	1950	Coarse grained, suitable for both medium and lower situations

(a) *Agricultural Research*

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
Indra sail ..	Dacca 1	T. S.	Winter	June to July	November to December	165	Green	Straw
Dhopi	„ 3	„	„	„	„	165	„	„
Jesobalam ..	„ 11	„	„	„	„	165	„	„
Daud In ..	„ 21	Hybrid	„	„	„	165	„	Cream
Latisail ..	„ 17	T. S.	„	„	„	165	„	Straw
Daudkhani ..	„ 9	„	„	„	„	165	Light purple	Gold
Tilakkachary ..	„ 7	„	„	„	„	180	Green	Straw
Chitraj	„ 23	Hybrid	„	„	„	160	Dark furrows	Brown
Hatisail ..	„ 13	T. S.	„	„	„	165	Dark purple	Black

(b) *Rice Research*

Kele	Chinsurah 2	T. S.	Autumn	June	September to October	126	Green	Black
Nagra (68/6) ..	Chin. 1	„	Winter	June to July	December	176	„	Straw
Bhasamanik ..	„ 3	„	„	„	„	170	„	„
Nagra (41/14) ..	„ 5	„	„	„	„	170	„	„
Patnai (298) ..	„ 7	„	„	„	„	170	„	„
Patnai (23) ..	„ 9	„	„	„	„	174	„	„
Kalma	„ 11	„	„	„	„	170	„	„
Rupsail ..	„ 13	„	„	„	„	174	„	„
Seeta sail ..	„ 15	„	„	„	„	172	Gold	Reddish brown
Badshabhog ..	„ 17	„	„	„	„	176	„	„
Kumargair ..	„ 19	„	„	„	December end	185	„	„

Station, Dacca—contd.

Awn	Size of paddy			Colour	Texture	Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)							
Tip	9·7	2·6	2·0	White	Sl. abd. white	..	..	..	3400	Medium-coarse, high yielding
nil	10·0	2·6	2·0	,,	,,	..	..	..	2850	Medium-grained, suitable for medium situations
,,	8·1	2·4	1·8	,,	Transl.	..	..	..	2460	Medium fine
Tip	9·9	2·1	1·8	,,	,,	..	..	..	2850	Early, fine-grained
nil	8·7	3·0	2·1	,,	Abd. white	..	..	..	2850	Coarse-grained, drought resistant variety with good yield
,,	8·9	1·9	1·7	,,	,,	..	..	..	2450	Fine grained
,,	8·6	3·3	2·1	,,	,,	..	..	..	2500	Coarse grained-suitable for lower situations
,,	8·4	2·6	2·0	,,	,,	..	..	..	1950	Early, suitable for double cropped land
Awn.	8·3	2·2	1·8	,,	Transl.	..	..	..	2450	Fine grained; scented

Station, Chinsurah

Awn	Length (mm.)	Breadth (mm.)	Thickness (mm.)	Colour	Texture	Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special features
nil	7·9	2·8	1·9	V. lt. red	Abd. white	Good	..	..	2000	Good early rice
,,	8·7	2·4	1·9	White	Transl.	Fair	..	..	2600	Fine grade quality rice
,,	8·7	2·2	1·8	,,	,,	,,	..	..	2800	Doing well under average conditions, trade rice
,,	8·5	2·6	1·9	,,	,,	Good	..	..	2700	
,,	11·1	2·7	2·1	,,	,,	,,	..	..	2900	Quality rice for, western market; non-lodging
,,	11·5	2·7	2·1	,,	,,	,,	..	..	2800	do.
,,	10·3	2·6	2·1	,,	,,	,,	..	..	2800	Good rice for export market
,,	8·8	2·2	1·8	,,	,,	,,	..	..	2000	Long fine type
,,	8·7	2·0	1·8	,,	,,	,,	..	..	2000	Long fin type for export market in India
,,	6·3	1·9	1·7	,,	,,	,,	..	..	2200	Scented rice
,,	8·9	3·7	2·5	,,	Abd. white	,,	..	..	2800	Coarse tall rice

(c) Rice Research

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
Bhutmuri ..	Chin. 36	T. S.	Autumn	June	September to October	110	Green P. tip	Black
Bad Kalamkati ..	,, 65	,,	Winter	June to July	,,	138	Green	Straw
Bad Kalamkati ..	,, 7	,,	,,	,,	,,	138	,,	,,
Katak Ind ..	,, 36	Hybrid	,,	,,	,,	144	,,	,,
Chanock sport ..	..	Mutations	,,	,,	,,	142	,,	,,
Boldar ..	..	T. S.	,,	,,	,,	156	,,	Gold
Dahijira ..	..	,,	,,	,,	,,	158	Green P. tip	Straw
Kaladubraj ..	..	,,	,,	,,	,,	158	Green	,,
Ajan	246	,,	,,	,,	,,	158	,,	,,
Kali kalma ..	..	,,	,,	,,	,,	158	Green P. tip	,,
Nonaram sail ..	..	,,	,,	,,	,,	155	Gold	Reddish brown
Manik-kalma ..	..	,,	,,	,,	,,	160	Green	Straw
Sindhur-mukhi ..	..	,,	,,	,,	,,	165	Green P. tip	Reddish brown
Raghu-sail ..	..	,,	,,	,,	,,	168	,,	,,
Basmati ..	..	,,	,,	,,	,,	165	,,	Straw
Randhunia-pagal ..	..	,,	,,	,,	,,	165	,,	,,

(d) Rice Research

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Fresh	Ripening
Chingrighusi ...	Barisal 1	S. P. S.	,,	,,	November to December	170	Green	Straw
Khairajali ..	,, 2	,,	,,	,,	,,	165	,,	,,

Station, Bankura

Awn	Size of paddy			Colour	Texture	Helling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special feature
	Length (mm.)	Breadth (mm.)	Thickness (mm.)							
nil	7·9	2·8	2·1	Red	Transl.	Good	..	..	2000	Good early paddy
,,	9·1	2·4	2·0	White	,,	,,	..	..	2400	Good rice with wide adaptations
,,	9·2	2·4	1·8	,,	,,	,,	..	..	2200	Fine rice, good for parboiling, long ear heads
,,	9·7	3·0	1·9	,,	Abd. white	,,	..	..	2500	A heavy yielding useful for puffed rice
,,	9·8	2·2	1·8	,,	Transl.	,,	..	..	2000	
Awned	8·7	3·0	2·0	,,	Abd. white	,,	..	..	2400	Good for puffed rice; heavy yielder with a wide range of adaptability though coarse
nil	8·1	3·1	2·1	Red	,,	,,	..	..	2200	
,,	8·5	2·5	2·1	White	Transl.	,,	..	..	2300	Good yielding
Awned	9·9	2·7	2·0	,,	,,	,,	..	..	2100	Useful for beaten rice; good yielder with wide range of adaptibility
,,	10·0	2·7	2·0	Red	Abd. white	,,	..	..	2200	
nil	8·3	2·2	1·8	White	Transl.	,,	..	..	2000	Fine grain
,,	8·4	3·1	2·2	,,	Abd. white	,,	..	..	2200	Coarse grain, useful for puffed rice
,,	9·2	3·0	1·9	,,	,,	,,	..	..	2200	
Awned	10·7	2·9	2·1	,,	,,	,,	..	..	2400	Heavy yielder eves a range of conditions
,,	8·3	2·4	1·9	,,	Transl.	,,	..	..	2000	Scented paddy for *pulao*
nil	7·9	2·3	1·8	,,	,,	,,	..	..	1500	Scented rice

Station, Barisal

nil	7·8	2·5	1·8	White	Transl.	Good	..	..	2800	
,,	8·2	2·6	1·9	,,	,,	,,	..	..	2800	

2. MADRAS

(a) *Paddy Breeding*

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
Kitchili samba ..	1 GEB. 24	Mutant	Winter	June	4th week November	150	Green	Straw
Peria kitchili ..	Co. 1	Hybrid	„	„	1st week December	150	„	„
Poombalai ..	1 Co. 2	*S. P. S.	„	„ October	2nd week December 4th week February	160	„	„
Vellai samba ..	1 Co. 3	„	„	June	2nd week December	180	„	„
Gobi anaikomban	2 Co. 4	„	„	„ October	3rd week January 3rd week February	200	Purple Spread	„
Chinna samba ..	1 Co. 5	„	„	June	2nd week December	180	Green	„
Sadai samba ..	2 Co. 6	„	„	„ October	1st week January 1st week February	190	„	„
Sadai samba ..	1 Co. 7	„	„	June	2nd week December	180	„	„
Anaikomban (Tinn)	1 Co. 8	„	„	„ October	2nd week January 1st week February	200	„	„
Red kar samba ..	1 Co. 9	„	Autumn Spring	June January	September April	110	„	„
Gobi kar ..	1 Co. 10	„	Autumn Spring	June January	October April	120	„	„ purple
Ayan Samba ..	2 Co. 11	„	Winter	June October	2nd week January 3rd week February	..	„	Straw
Sendhinayagam ..	Co. 12	„	„	June October	3rd week January 3rd week February	200	Piebald Gold.	Gold
Velai kodai ..	1 Co. 13	„	Autumn Spring	June February	September April	110	Green P. tip	Straw

*S.P.S.—Single plant selection; Transl.—Translucent; and Hard. Duration reckoned upto ripening.

PROVINCE

Station, Coimbatore

Awn	Size of paddy			Rice		Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)	Colour	Texture					
nil.	7·8	2·4	1·8	White	Transl.	Good	Good	10–30	3000 to 5000	Fairly resistant to *Piricularia*; non-shedding and resists stem borer. A premier strain adapted to a variety of conditions
,,	8·5	2·6	1·9	,,	,,	,,	,,	20	,,	Non-shedding and resists stem borer; similar to GEB. 24 but slightly coarser and later in duration
,,	7·5	2·5	1·9	,,	,,	,,	,,	8–10	,,	Stands transplanting in October. Sheds grains if not harvested in time
,,	8·4	2·7	2·0	,,	,,	,,	,,	9	4000	..
,,	8·6	2·7	2·0	,,	,,	,,	,,	10	,,	Highly resistant to *Piricularia oryzae* tall growing, non-lodging; useful for making puffed rice.
,,	7·9	2·6	1·9	,,	,,	,,	,,	12	3500 to 5000	..
,,	7·7	2·8	1·9	,,	,,	,,	,,	10	4000	Tall growing with good tillering
,,	7·9	2·7	1·9	,,	,,	,,	,,	8–10	3000 to 5000	Profuse tillerer and responds to good cultivation
,,	8·8	2·6	1·9	,,	,,	,,	,,	17	..	Good quality rice
,,	7·4	3·2	2·2	Red	Soft	Fair	Ordy	14	3000	Grown as an autumn and spring variety under channels in Tambaraparni valley
,,	7·8	3·0	2·0	White	,,	,,	,,	17	..	do.
,,	8·2	2·6	1·9	,,	Transl.	Good	Good	13	..	Good quality rice; tall growing but weak straw
,,	..	..	..	,,	,,	,,	,,	13	3000	A variety very popular in Tambaraparni valley
,,	7·9	3·1	2·0	,,	Soft	Fair	Ordy	19	3000	Grown both as an autumn and spring crop under channels

(a) *Paddy Breeding*

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
Vellai samba ..	[1] Co. 14	Hybrid	Winter	June	December end	200	Green	Straw
Jadamolagolu kulu	[1] Co. 15	..	..	.. October	3rd week January 3rd week February	210	Dirty furrows	Brown
Bontha molo-Golu-kulu.	[1] Co. 16	..	..	June Ocotber	3rd week January 3rd week February	210	..	..
Chinna vadan samba	[1] Co. 17	S. P. S.	,,	June	December end	200	Green	Straw
Vellai kar ..	[1] Co. 18	..	Autumn Spring	.. January	Mid October Mid May	125	..	..
Sirumanian (Chingleput)	[1] Co. 19	..	Winter	June October	3rd week January February end	210	Dirty furrows	Brown
Tellasasanna Vadlu	[1] Co. 20	..	Winter Spring	July January	Mid October Mid May	130 120	Green	Straw

(b) *Agricultural Research*

Red sirumani ..	[1] Adt. 1	S. P. S.	Winter	July September	2nd week January 1st week February	175 160	Dirty furrows	Brown
White sirumani ..	[1] Adt. 2	..	..	July September	1st week January January end	165 150	Green	Straw
Kuruvai ..	Adt. 3	,,	Autumn	June	1st week September	95	Dirty furrows	Brown
Kuruvai ..	[2] Adt. 4	..	..	..	2nd week September	100	..	..
Nellore samba ..	[3] Adt. 5	,,	Winter	July September	3rd week January 3rd week February	180 170	..	,,
Red ottadan ..	Adt. 6	,,	,,	June	February end	220	Dark-gold	Dark-gold

Station, Coimbatore—contd.

Awn	Size of paddy			Colour	Texture	Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)							
Sl. Ten	8·6	2·6	2·0	White	Transl.	Fair	Good	10	3000 to 4000	Stands submersion of 3 ft. to 4 ft. if sown early ; on-lodging
nil.	7·7	2·9	2·0	,,	,,	Good	,,	[illegible] 50	..	Resistant to *Piricularia* ; stiff straw and bunched head ; good quality fit for preparing raw rice.
,,	8·1	3·1	2·0	,,	,,	,,	Fair	,,	..	Resistant to *Piricularia*; stiff straw and bunched ears; fit for par-boiling
,,	8·1	2·8	2·0	,,	,,	Fair	Ordy	10 to 25	2500	Stands drought, earlier than the local bulk; straw stiff with bunched ear-heads ; popular in Chinglepet district
,,	8·1	2·9	2·0	,,	Soft	,,	,,	12	2700	A week earlier than the local bulk
,,	7·7	2·8	2·0	,,	Transl.	,,	Fair	12	..	Somewhat resistant to *Piricularia* and drought; popular in Chinglepet
,,	9·0	2·8	2·0	,,	,,	,,	,,	9	3500	Responds to heavy manuring ; yielding upto 5000 lb.

Station, Aduturai

Awn	Length (mm.)	Breadth (mm.)	Thickness (mm.)	Colour	Texture	Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special features
nil.	6·4	3·1	2·1	White	Medium	Fair	Good	16	3000 2500	Converted into par-boiled rice and exported to Ceylon
,,	5·8	2·9	2·0	,,	Transl.	Good	,,	10	2800 2400	Consumed by richer classes ; good quality rice
,,	7·7	3·0	2·0	,,	Soft	Fair	Poor	..	3200	Earlier than the cultivators' bulk ; grown in the first crop season
,,	7·9	3·0	2·0	,,	,,	,,	,,	12	3800	..
,,	8·1	3·1	2·0	,,	Transl.	Good	Good	25	2800	Somewhat coarser than the typical Nellore samba
,,	7·7	3·0	2·0	,,	,,	Fair	Fair	13	2000	It is grown mixed with a short duration variety

(b) *Agricultural Research*

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
White ottadan ..	Adt. 7	S. P. S.	Winter	June	February end	220	Dark gold	Dark gold
Early sirumani	1 Adt. 8	Hybrid	,,	July September	December end January end	150 140	Green	Straw
Poonkar ..	2 Adt. 9	S. P. S.	Autumn	June	Mid September	120	,,	,,
Korangu samba ..	1 Adt. 10	,,	Winter	July	1st week January	165	Dirty furrows	Brown
Nellore Samba ..	1 Adt. 11	,,	,,	July	3rd week January	175	Dirty furrows	Brown
Chitrakali ..	2 Adt. 12	,,	Autumn	Early June	2nd week September	115	Green	Straw
Sanna samba ..	3 ,, 13	,,	Winter	July	1st week January	160	,,	,,
Vellai kar ..	3 ,, 14	,,	Autumn	Early June	1st week September	115	,,	,,
Senkuruvai ..	2 ,, 15	Mutant	,,	,,	,,	110	,,	,,
Kona kuruvai ..	2 ,, 16	S. P. S.	,,	,,	2nd week September	115	,,	Lt. gold
Muthu samba ..	,, 17	,,	Winter	July	1st week January	165	Dirty furrows	Brown
Vellai Kuruvai ..	2 ,, 18	,,	Autumn	June	3rd week September	125	Green	Straw
Sarapalli ..	3 ,, 19	,,	,,	,,	1st week September	109	,,	,,
Kuruvai ..	1 ,, 20	Hybrid	,,	,,	,,	105	,,	,,

(c) *Agricultural Research*

Bontha akkullu	1 Mtu. 1	S. P. S.	Winter	May June	4th week November	170	Dirty furrows	Brown
Potti akkullu ..	2 ,, 2	,,	,,	,,	,,	170	,,	,,

Station, Aduturai—contd.

Awn	Size of paddy			Colour	Texture	Hulling quality	Cooking quality	Percentage increase yield over control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)							
,,	7·6	3·0	2·0	White	Transl.	Fair	Fair	13	2000	It is grown mixed with a short duration variety
,,	6·0	2·9	2·0	,,	,,	Good	Good	8	2900 2300	Earlier than Adt. 2 preferred as a second crop after *Kuruvai*
,,	8·2	2·8	1·9	,,	Medium	Fair	Fair	15	4000	Preferred where season is early
,,	·27	3·0	2·0	,,	Sl. abd. white	Good	Good	9	4000	Exported as parboiled rice
nil	7·4	2·8	1·9	,,	Transl.	Good	Good	6	3400	Good quality rice grain finer than Adt. 5
,,	8·7	2·9	2·0	,,	Medium	Ordy	Fair	9	3500	Stands irregular water supply, suitable for well-irrigated rice lands
,,	8·1	2·6	1·9	,,	Transl.	Fair	,,	7	3900	
,,	8·8	2·9	2·0	,,	Medium	Ordy	,,	9	4000	
,,	7·8	2·9	2·0	,,	,,	,,	,,	25		
,,	7·7	1·9	1·5	,,	Transl.	,,	,,	25	3700	Fine early rice
,,	7·8	3·4	2·2	,,	,,	Fair	,,	10	3700	Stands somewhat submersion
,,	8·1	3·0	2·0	,,	Soft	Ordy	,,	12	3600	
,,	7.9	2·9	2·0	,,	,,	,,	,,	19	3800	
,,	5·9	2·7	1·8	,,	,,	,,	,,	25	4200	Kuruvai with round grain liked by cultivators.

Station, Maruter

nil	8·0	2·8	2·0	White	Abd. white	Fair	Good	20	2800 to 3700	A cosmopolitan variety standing slight salinity, floods and suited to soils of average fertility
,,	7·9	2·7	1·9	,,	,,	,,	,,	16	2800 to 3500	Short growing and hence suited to rich soils so that it may not lodge

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
Potti basangi ..	1 Mtu. 3	S.P.S.	Winter	May-June	3rd week October	140	Green	Straw
Pedda basangi ..	1 ,, 4	,,	,,	,,	4th week October	145	,,	,,
Bontha-kirshna-kantwkalu	1 ,, 5	,,	,,	,,	November end	170	,,	,,
Potti atragada	,, 6	,,	,,	,,	,,	170	Dirty furrows	Brown
Gutti Kusuma ..	1 ,, 7	,,	,,	,,	2nd week December	180	Green	Straw
Vanki sannam ..	1 ,, 8	,,	,,		,,	180	,,	Gold
Garika Sannavari	2 ,, 9	,,	Spring	December January	April end	120	Green P. tip	Straw
Sanna krishna-kantu-kalu	1 ,, 10	,,	Winter	May to June	4th week November	170	,,	,,
Konamani ..	,, 11	,,	,,	,,	November end	170	,,	,,
Pedda atragada ..	1 ,, 12	,,	,,	,,	2nd week December	180	Dirty furrows	Brown
Delhi-bhogum ..	,, 13	,,	,,	,,	,,	180	Light gold	Light gold
[illegible] atragada	,, 14	,,	,,	,,	November end	170	Dirty furrows	Brown

Station, Maruter—contd.

Awn	Length (mm.)	Breadth (mm).	Thickness (mm)	Colour	Texture	Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special features
nil	8·1	2·7	2·0	White	Medium-hard	Ordy	Good	12	3000 to 4500	Though medium duration responds to heavy manuring; stiff straw and erect growing
,,	8·8	2·6	2·0	,,	,,	,,	,,	9	3000 to 4000	Stands indifferent water supply
,,	7·8	2·6	1·8	,,	Hard	Good	,,	12	2800 to 3400	Premier variety of Godavary delta with good tillering and uniform yields
,,	7·9	2·8	2·0	Dull white	,,	,,	,,	16	2800 to 3000	Short growing, non-lodging; suitable to low lying areas. Supposed to be more wholesome
,,	8·6	2·7	2·0	White	,,	,,	,,	16	3500	Stands indifferent supply of water; stiff, non-lodging and non-shedding with bunched ear heads
,,	8·7	2·5	1·9	,,	Transl. hard	,,	,,	10	2800	Good quality rice, less shedding and less sterility than local; stands indifferent water supply
,,	8·1	2·9	2·0	White	Abd. white	Fair	,,	18	3000	Earlier than local and is a favourite for second crop in the Godavary delta, has a shedding tendency
,,	7·5	2·3	1·7	Dull white	Hard	Good	,,	10	2800 to 3200	Fine quality rice, short growing, non-lodging, adapted to rich lands. Subject to false smut in some seasons
,,	8·1	2·7	2·0	Brownish	,,	,,	,,	30	3000	Stands submersion as well as indifferent water supply
,,	8·2	2·8	2·1	White	,,	,,	,,	8	3200	Rice esteemed as wholesome; sheds more easily than other varieties
,,	8·2	2·2	1·7	,,	,,	,,	,,	10	2800	Good quality fine rice
,,	7·9	2·7	2·0	Brownish	,,	,,	,,	25	3200	Vigorous growing with yellowish green vegetation; does not lodge

(c) *Agricultural Research*

Name of variety	Number		Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
								Fresh	Ripening
Dalwa sannam ..	1 Mtu.	15	Hybrid	Spring	December to January	1st week May	130	Green P. Tip	Straw
Badava kusuma ..	,,	16	,,	Winter	May to June	1st week December	170	,,	,,

(d) *Agricultural Research*

Name of variety	Number		Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Fresh	Ripening
Aryan ..	1 Ptb.	1	S. P. S.	Autumn	May to June	Mid. October	145	Dirty furrows	Brown
Ponnaryan ..	1 ,,	2	,,	,, Winter	,,	October	135	,,	,,
Eravapandy ..	1 ,,	3	,,	,,	September to October	Mid February	130	,,	,,
Vellari	1 ,,	4	,,	,,	,,	February end	140	Green	Straw
Veluthari-kayama	1 ,,	5	,,	Autumn	May to June	October	140	Piebald Gold	Gold
Atikraya ..	2 ,,	6	,,	Winter	September	October February end	145	Dark dirty furrows	Brown
Parambu vattan ..	1 ,,	7	,,	Autumn	May to June	End of September	125	Green	Black
Chuvannari-thavalakkannan	1 ,,	8	,,	,,	,,	,,	130	Green P. tip	Straw
Veluthari thavalakkannan	1 ,,	9	,,	,,	,,	Mid October	145	,,	,,
	1 ,,	10	,,	Spring	February	May	100	Dirty furrows	Brown
Halliga ..	3 Ptb.	11	,,	Autumn	May-June	Mid October	145	Green	Straw
Chitteni ..	,,	12	,,	Winter	Sept. Oct.	Mid February	130	Dry furrows	Black
Kayama ..	1 ,,	13	,,	Autumn	May June	1st week October	135	Green	Straw
	1 ,,	14	,,	,,	,,	September end	130	,,	,,
Kavingin—poothala (late)	1 ,,	15	,,	Winter	June July	1st week January	165	Green P. tip	,,
Kavingin—poothala (early)	1 ,,	16	,,	,,	,,	..	155	,,	,,

Station, Maruter—contd.

Awn	Size of paddy			Rice		Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)	Colour	Texture					
nil	8·3	2·5	1·9	White	Medium-hard	Fair	Good	17	3500	Less shedding than Mtu. 9 ; stands early planting
,,	8·5	2·8	2·0	Brownish	,,	,,	,,	..		Suited to ill-drained soils ; subject to inundation of 4 ft. to 5 ft. of water ; non-lodging and tall growing

Station, Pattambi

,,	8·2	2·9	1·0	Red	Soft	Fair	Good	15	3000	
,,	8·8	3·0	2·0	,,	,,	,,	Fair	,,	2500	Both autumn as well as winter rice
,,	2·6	2·8	2·0	,,	,,	,,	,,	8	1800	
,,	8·1	3·1	2·1	,,	,,8	,,	,,	32	2200	Heaviest of second crop varieties on west coast
,,	8·4	2·9	2·0	,,	,,	,,	,,	15	2700	Requires good water supply
,,	8·0	3·1	2·0	,,	,,	,,	,,	18	2000	Tall growing ; a popular second crop variety
Awned	8·0	2·8	2·0	,,	,,	,,	,,	13	2400	Stands irregular water supply and also salinity to some extent
nil	7·3	2·9	2·0	,,	,,	,,	,,	17	2500	Earlier than local
,,	7·4	2·9	2·0	White	,,	,,	,,	13	2000	Non-shedding and non-lodging
,,	8·1	2·9	2·0	Red	,,	,,	,,	..	2000	Grown in all the three seasons in west coast ; stands indifferent water supply
,,	8·0	2·8	2·0	White	Medium hard	,,	,,	..	2500	
,,	7·7	2·9	2·0	Red	Soft	,,	,,	13	2000	
,,	7·3	3·0	1·9	,,	,,	,,	,,	21	2500	
,,	8·2	2·7	1·8	White	,,	,,	,,	19	2500	Good for beaten rice
,,	7·9	2·3	1·7	,,	Transl.	Good	Good	18	3000	Grown in submersible areas ; tall and stiff straw having bunched heads ; good quality rice
,,	8·2	2·2	1·7	,,	,,	,,	,,	15	3000	Shorter in duration than Ptb. 15 but has similar properties.

(e) *Rice Research Station, Berhampur*

Name of variety	Number		Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
								Fresh	Ripening
[illegible]	Bam.	1	S.P.S.	Winter	June July	3rd week November		Green	Straw
[illegible]	..	3	..	..	..	November end		..	..
[illegible]	..	4	..	..	..	..		..	..
[illegible]	..	5	..	..	..	1st week December	..	Piebald gold	Piebald gold
Ratnachuli	..	6	..	..	..	..	..	..	..
[illegible]	..	7	..	..	..	..		Green	Straw
do. ..	..	8	..	..	..	..	.	Green P. tip	..
[illegible] ..	..	9	..	..	..	..	.	Green	..
do. ..	..	10		..		..	..	..	..

(f) *Agricultural Research*

[illegible]	Sbk.	1	S.P.S.	Winter	May June	3rd week November	170	Green	Straw
do. ..	Sbk.	2	..	..	..	..	..	..	..
[illegible]	..	4	..	..	..	4th week November	175	..	..
[illegible]	..	11	..	..	..	1st week December	180	Dirty furrows	Brown in furrows
[illegible]	..	12	..	Summer	January	April	120	Green	Straw
[illegible]	..	13	..	Winter	May June	1st week December	180	..	..
Geb. N × 3	..	7	Hybrid	..	..	November end	[illegible]	..	..
Geb. N × 70 ..		18	.	.	..	..	175	..	..

1—extremely popular and largely in demand
2—suitability restricted to small areas
3—not popular with cultivators

(before it was transferred to Orissa)

Awn	Size of paddy			Colour	Texture	Hulling quality	Cooking quality	Percentage increase over local control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)							
nil	9·1	2·7	2·0	Lt. red	Transl.	Good	Fair	19	2400 to 2600	Short growing, does not lodge, heavy tillerer, withstands drought
,,	8·6	2·4	1·9	White	,,	,,	Good	19	,,	
,,	8·5	2·4	1·9	,,	,,	,,	,,	16	,,	Good quality rice, stands indifferent water supply; premier strain of Ganjam and Vizag. districts; finding favour in the central districts of Madras Province
,,	8·2	2·4	1·8	,,	,,	,,	,,	14	,,	Good quality rice and wholesome stiff straw
,,	8·0	2·4	1·8	,,	,,	,,	,,	15	,,	do.
,,	8·3	2·4	1·9	,,	,,	,,	,,	19	,,	Stiff straw, very bunched ear head suited to only rich soils
,,	8·1	2·6	1·9	,,	,,	,,	,,	14	,,	do.
,,	9·0	2·0	2·0	,,	,,	,,	,,	24	3000	Robust, coarse vegetation and does not lodge; stands submersion to some extent
,,	8·5	2·7	2·0	,,	,,	,,	,,	17	2500	do.

*Station, Samalkot**

Awn	Length (mm.)	Breadth (mm.)	Thickness (mm.)	Colour	Texture	Hulling quality	Cooking quality	Percentage increase over local control	Yield per acre (lb.)	Special features
nil	8·8	3·1	2·3	White	Transl.	Good	Fair	10	3150	Suited for the clay soil types of East Godavary delta
,,	7·9	2·8	2·1	,,	,,	,,	,,	16	3000	Suited to well-drained soils finer than the above
,,	8·2	2·7	1·9	,,	Sl. abd.	,,	,,	14	2800	
,,	7·8	2·4	1·7	,,	Transl.	,,	,,	6	3000	Fine grain, suited to high level areas
,,	8·3	2·9	2·1	,,	Abd. white	Fair	Fair	5	2200	Grown in second crop season
,,	8·6	2·7	2·0	,,	Transl.	Good	Good	28	5000	Heavy yielding, suitable to heavy soil of the delta
,,	7·8	2·4	1·9	,,	,,	,,	,,	12	5000	Suitable to high level soils of Godavary coastal delta
,,	7·8	2·6	1·9	,,	,,	,,	,,	22	4500	do.

---

* Strains evolved by the Circle Officers concerned independent of the Paddy Specialist.

(g) *Agricultural Research*

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
Garudan Samba ..	Palur 1	S.P.S.	Winter	August	January	..	Piebald gold	Reddish brown
Caitrakali ..	,, 2	,,	Autumn	June	September	..	Green	Straw

(h) *Agricultural Research*

Maharajabhogum	,, 4	S.P.S.	Winter	June-July	Mid-December	160	Light dirty furrows	Light brown
Bangaruthegalu ..	,, 9	,,	,,	,,	,,	,,	Green	Straw

* Strains evolved by the Circle Officers concerned

Station, Palur*

Awn	Size of paddy			Colour	Texture	Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)							
nil	8·1	3·1	1·9	White	Transl.	Fair	Good	..	..	
,,	8·4	3·2	2·7	,,	Abd. white	Fair	Fair	30	3100	

Station, Anakapalli*

Awn	Size of paddy			Colour	Texture	Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)							
nil	7·8	2·1	1·9	White	Transl.	Good	Good	..	2500	Fine rice of good quality
Tendency	9·2	2·5	2·0	,,	,,	,,	,,	..	2500	Strong growing ; does not lodge

independent of the Paddy Specialist

3. BIHAR

Rice Research

Nome of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
Dahia ..	115 B.K.	T.S.	Winter	June	2nd week November	150	Light dirty furrows	Brown
Jhulansar ..	141 B.K.	,,	,,	,,	3rd week November	160	Gold	Rich brown
Motisal ..	16 B.K.	,,	,,	,,	3rd week November	160	Light dirty furrows	Brown
Dahia ..	88 B.K.	,,	,,	,,	,,		Dirty furrows	Brown
Kessore ..	36 B.K.	,,	,,	,,	November end	170	Green	Straw
Dahia ..	76 B.K.	,,	,,	,,	,,		Light dirty furrows	Brown
Kessore ..	498-2A	,,	,,	,,	,,		Green	Straw

PROVINCE

Station, Sabour

Awn	Size of paddy			Colour	Texture	Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)							
Nil	8·6	2·6	2·0	White	Transl.	Fair	Good	12	1890	Thin culm and liable to lodge ; grown under diverse soil conditions
,,	8·8	2·8	2·0	,,	,,	,,	,,	12	1870	
,,	8·2	2·7	2·0	Light red	,,	,,	,,	10	1870	Tendency to lodge
Tipped	8·7	2·8	2·0	,,	,,	,,	,,	9	2110	
,,	9·8	2·7	2·0	White	,,	,,	,,	18	1830	
,,	8·7	2·8	2·0	,,	,,	,,	,,	11	2000	
..	9·5	2·4	1·9	Very light red	,,	,,	,,	..	2050	

4. UNITED

Rice Research

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
(Early Group)								
Rajbhog ..	N. 22	T.S.	Autumn	Mid June	September end	90	Green P. tip.	Straw
Banki ..	N. 27	,,	,,	,,	,,	90	Green	,,
Baljati ..	N. 32	,,	,,	,,	3rd week September.	84	,,	,,
Twandwa ..	Ch. 10	China	,,	,,	,,	83	,,	,,
Hansraj ..	A-64	T.S.	,,	,,	,,	85	,,	,,
Hansraj ..	T. 136	,,	,,	,,	End September.	93	,,	,,
Medium Group								
Ramjiwain ..	T. 1	,,	,,		,,	98	Light gold	Light gold
Basmati (Dehra-Dun)	T. 3	,,	,,	,,	2nd week October	115	Green brown tip	Straw
Jhona or Chittamunji	T. 29	,,	,,	,,	1st week October	110	,,	,,
Sondhi ..	T. 43	,,	,,	,,	End September	102	,,	,,
Chaul ..	T. 21	,,	,,	,,	1st week October	110	,,	,,
Late group								
Duniapat ..	T. 9	,,	Winter	,,	2nd week November	155	Green P. tip	,,
*Bansi ..	T. 17	,,	,,	,,	1st Week November	145	,,	,,
*Bansi ..	T. 22-A	,,	,,	,,	,,	155	,,	,,
Kalasukdas ..	T. 23	,,	,,	,,	2nd week November	150	Gold P. tip	Reddish brown
*Anjee ..	T. 26	,,	,,	,,	,,	,,	Green	Straw
*Jabda ..	T. 56	,,	,,	,,	3rd week November.	165	Green P. tip	,,
*Bhenslot ..	T. 100	,,	,,	,,	2nd week November.	150	,,	,,
	H. 108	Hybrid						
	H. 33	,,						
	H. 755	,,						

* Types isolated by Economic Botanist, Cawnpore, before the Rice Research Scheme financed by India.

PROVINCES

Station, Nagina

Awn	Size of paddy			Rice		Hulling quality	Cooking quality	Per centage increase in yield over control	Yield per acre (lb.)		Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)	Colour	Texture				Broad cast	Transplanted	
nil	7·5	2·7	2·0	White	..	Fair	Fair	..	1950	..	Early, drought resisting; both broadcast and transplanted
,,	7·4	2·7	1·8	,,	Transl	,,	,,	..	1900	2400	
,,	8·2	2·7	1·8	,,	,,	,,	,,	..	1900	2000	Early rice suitable for high level areas
,,	7·8	3·0	2·1	,,	Abd. white	,,	Average	..	1900	2800	Coarse grain but early and heavy yielding
Tend	..	..	..	,,	,,	,,	,,	..	1950	..	Drought resisting
Point	8·8	2·1	1·8		Transl	Good	Good	..	..	2750	Suitable to drier areas erect but lodges in rich soils; fine grain
,,	9·8	2·0	1·7	,,	,,	,,	,,	..	..	2650	Lodges in rich soils; fine rice
,,	9·8	2·0	1·8	,,	,,	,,	,,	..	..	..	Tall growing, scented; lodging in rich soils, superior quality known as Dehradun in trade
nil	9·8	2·4	2·0	,,	,,	,,	,,	..	..	2800	Lodging in rich soils; suited to canal tracts with good cooking quality and taste
Full	8·4	2·2	1·8	,,	,,	Fair	,,	..	..	2800	Lodges but suited for pig and bird infested areas
nil	10·0	2·3	1·9	,,	,,	Good	,,	..	..	2800	Erect; suited to preparation of beaten rice; useful for saline (*Patri*) lands
,,	9·3	2·1	2·0	,,	,,	,,	,,	..	..	2300	Scented rice, long fine.
,,	9·9	2·2	1·9	,,	,,	Fair	Average	..	..	2900	Long fine
Awned	9·8	2·7	1·9	,,	,,	Good	Good	..	..	2900	This is in great demand in canal-fed areas
,,	9·4	2·2	1·4	,,	,,	,,	,,	..	..	2500	Fine grain with good cooking quality; scented
Tend	7·7	1·9	1·7	,,	,,	,,	,,	,,	..	2500	Reputed to do fairly well on poor or saline (*Usar*) lands; fine grain
Awned	9·6	2·8	2·2	,,	Abd. white	Average	Average	..	..	3400	Heavy yielding, late strain in great demand in irrigated areas
nil	7·8	3·2	2·4	,,	,,	,,	,,	..	..	3000	Tall with heavy ear heads coarse.

Council of Agricultural Research was started.

5. CENTRAL

Rice Research

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
*Nungi	R 2	T.S.	Autumn	Mid-June	3rd week October	123	Green	Straw
Sultugurumatia	R 3	,,	,,	,,	4th week October	130	Green P. tip	,,
*Surumatia	R 4	,,	,,	,,	1st week November.	145	,,	,,
*Ludko	R 5	,,	,,	,,	2nd week November.	148	Dirty furrows	Brown
Budhiabako	R 6	,,	,,	,,	3rd week November.	154	Green	Straw
Ajan	R 7	,,	,,	,,	,,	156	,,	,,
Benisar	R 8	,,	,,	,,	4th week November.	166	,,	,,
*Luchai	R 9	,,	,,	,,	,,	163	,,	,,
Chhatri	R 10	S.P.S.	,,	,,	1st week November	145	,,	Brown
Dubraj	R 11	,,	,,	,,	2nd week November	147	,,	Straw
Banspatri	R 12	,,	,,	,,	,,	150	Green P. tip	,,
Kurbimohar	R 13	,,	,,	,,	3rd week November	157	Green	Brown
Badshahbhog	R 14	,,	,,	,,	4th week November	162	,,	Rich brown
Chinoor	R 15	,,	,,	,,	1st week December	169	,,	Straw
Kantibudhiabako	Cross 19	Hybrid	,,	,,	3rd week November	154	,,	,,
	Cross 116	,,	,,	,,	2nd week November.	148	Dark gold	Dark gold
	Cross 1	,,	Autumn	,,	3rd week October	125	Dirty furrows	Brown
	Cross 2	,,	Winter	,,	2nd week November	148	,,	,,
	Cross 5	,,	,,	,,	4th week November.	162	..	..

*Released by the Economic Botanist, Nagpur, before the Rice Research Scheme financed by Indian

PROVINCE

Station, Raipur

Awn	Size of paddy			Rice		Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Sepcial features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)	Colour	Texture					
nil	..	..	..	White	Abd. white	Fair	Fair	..	1300	Withstands drought to some extent
,,	..	..	..	,,	Transl	,,	,,	..	1630	Highest yielding among early strains
,,	..	..	..	,,	,,	Good	Good	..	1500	
,,	..	..	..	,,	,,	,,	,,	..	1650	Does well also on heavy soils
,,	..	..	..	,,	,,	,,	,,	..	1620	Fine quality rice known as *Hansa* in trade; drought resisting.
,,	..	..	..	,,	,,	,,	,,	27	1870	Best among late strains ; can replace Gurmatia
,,	..	..	..	,,	,,	,,	,,	..	1810	High yielding ; does well on heavy soils also
,,	..	..	..	,,	Abd. white	Fair	,,	..	1680	Breaks in milling and hence suitable for parboiling ; stiff, erect straw ; non-lodging
,,	..	..	..	,,	Transl	Good	Good	..	1250	Finegrain, scented
Awned	..	..	..	,,	,,	,,	,,	..	1380	Fine grain, scented
nil	..	..	..	,,	,,	,,	,,	..	1500	High yielding scented rice.
,,	..	..	..	,,	,,	,,	,,	..	1580	Non-shedding, scented; grown in parts of Madras.
,,	..	..	..	,,	,,	,,	,,	..	1400	Short fine grain with scent.
Point	..	..	..	,,	,,	,,	,,	..	1570	Non-shedding ; trade variety with fine rice quality ; lightly scented.
nil	9·22	2·43	..	,,	,,	,,	,,	..	2000	Good quality rice
,,	8·29	3·37	..	,,	Abd. white	,,	Fair	10	1990	Cosmopolitan variety coarse but high yielding, suitable for puffed rice
,,	8·46	3·07	..	,,	,,	,,	,,	..	1100	Purple leaved; easily distinguished from wild rice
,,	8·35	3·46	..	,,	,,	,,	,,	..	1450	do.
,,	7·84	2·69	..	,,	,,	,,	,,	..	1550	do.

Council of Agricultural Research was started in 1932.

6. ASSAM

(a) *Paddy Research*

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
Broadcast aus								
Tepi Dumai ..	D. 1386	T. S.	Autumn	March to April.	1st week September.	78	Dirty furrows.	Black
Baurashmurali ..	M. 36-30	,,	,,	,,	September end.	100	Green	Straw
Koi murali ..	M. 142	,,	,,	,,	Mid September.	93	,,	,,
Chengri ..	C. 148-1	,,	,,	,,	,,	90	,,	Gold
Dhalajali ..	M. 175-1	,,	,,	,,	3rd week September.	95	,,	Straw
Transplanted Aus								
Basmati ..	As. 3	,,	,,	April to May.	1st week October.	112	,,	,,
Basantbahar ..	As. 24-1	,,	,,	,,	End September.	102	Gold	Gold
Kasalath ..	As. 2	,,	,,	,,	1st week October	110	Green	Straw
Jaria aus ..	As. 46	,,	,,	,,	2nd week October.	118	Dirty furrows.	Brown
Hybrid aus. ..	Asc. 536-143	Hybrid	,,	,,	End September.	106	Green	Straw
Latisail ..	S. 22	T.S.	Winter	June to July	December end	165	,,	,,
Nagrasail ..	S. 56	,,	,,	,,	,,	,,	,,	,,
Prosadbhog ..	S. 61	,,	,,	,,	Mid December	155	,,	,,
Badshabhog ..	S. 55	,,	,,	,,	,,	160	,,	,,
Dhepisail ..	S. 161	,,	,,	,,	December end	170	,,	,,
Vijoysail ..	Sc. 54-60	,,	,,	,,	Mid December	155	,,	,,
Kerr sail ..	Sc. 94-47	,,	,,	,,	December end	165	,,	,,
	Sc. 671-16	Hybrid	,,	,,	December end	,,	,,	,,
Asra								
Sail badal ..	Ar. 1	T.S.	,,	May to June	Mid February	195	,,	,,
Laki ..	Ar. 2	,,	,,	,,	February end	200	,,	,,
Dhola badal ..	Ar. 108-1	,,	,,	,,	,,	205	,,	,,
Hybrid ..	Arc. 353-148	Hybrid	,,	,,	June end.	185	,,	,,

PROVINCE

Station, Karimganj

Awn	Size of paddy			Colour	Texture	Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)							
nil	7·9	2·6	..	Red	Abd. white	Mod	Poor	..	1850	
Point	8·0	2·6	..	,,	,,	,,	,,	..	2240	
nil	7·1	3·0	..	,,	,,	,,	,,	..	2080	
,,	8·3	2·7	..	,,	,,	,,	,,	..	2080	
,,	7·6	2·7	..	,,	,,	,,	,,	..	2240	
,,	7·3	2·7	..	White	Transl.	..	..	..	2400	Non-lodging, good quality rice; medium fine
,,	8·3	1·9	..	,,	,,	..	..	..	2080	Fine
Tendency	7·8	2·5	..	Red	,,	..	..	..	2400	
nil	8·4	2·6	..	,,	Abd. white	..	..	..	2560	Does not lodge; erect habit
,,	7·7	2·5	..	White	Transl.	..	..	..	2400	
,,	8·5	3·0	..	,,	Abd. white	..	..	..	3200	Heavy yielder; stiff straw; does not lodge cosmopolitan
,,	8·6	2·2	..	,,	Transl.	..	..	..	2800	Fine; long grain; susceptible to desease
,,	7·7	2·4	..	,,	,,	..	..	..	2400	Medium fine
,,	6·6	2·0	..	,,	,,	..	..	Good	2560	Small, fine grain
,,	9·8	3·0	..	,,	Abd. white	..	..	Aver	3300	Non-lodging, coarse, long grain
,,	8·2	2·8	..	,,	Transl.	..	..	..	3040	Coarse grain
,,	8·8	2·6	..	,,	,,	..	..	..	3360	Best winter paddy; non-lodging; medium fine
,,	9·7	2·3	..	,,	,,	..	..	..	3200	Medium, fine, non-lodging
Point	8·0	3·2	..	,,	Abd. white	..	..	..	3400	Coarse, thrives in 2 ft. to 6 ft. of water.
nil	8·3	2·5	..	,,	,,	..	..	..	3200	do.
,,	8·2	3·0	..	,,	,,	..	..	..	3840	Coarse, very late; thrives in 3 ft. to 7 ft. of water
,,	8·6	3·0	..	,,	,,	..	..	..	3360	Coarse; uniform ripening; thrives in 2 ft. to 4 ft. of water

(b) *Paddy Research*

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
Aus								
Rangadaria ..	As. 86	T.S.	Autumn	March to April.	3rd week September	94	Dirty furrows	Brown
Farma ..	As. 35	,,	,,	,,	1st week October	109	Green	Straw
Dubai chenga ..	As. 48	,,	,,	,,	September end	103	,,	,,
Garem ..	As. 201.	,,	,,	,,	,,	100	Green	Gold
Fapori ..	..	,,	,,	,,	3rd week September	93	Dirty furrows.	Brown
Sail								
Laudumra ..	S. 126	,,	Winter	June to July.	Mid December	158	Green P. tip. Geeen	Brown
Latamaguri ..	S. 115	,,	,,	,,	3rd week December	163		Straw
Johori ..	S.L. 240	,,	,,	,,	Mid December	158	,,	,,
Bengali joha ..	S.J. 226	,,	,,	,,	End December	168	Gold	Gold
Lakshmi joha ..	S.J. 311	,,	,,	,,	,,	160	Dirty furrows.	Brown
Ahomsail ..	S.L. 70(A)	,,	,,	,,	1st week December.	150	Green	Straw
Comiribora ..	S.B. 279	,,	,,	,,	Mid December.	160	Gold	Gold

(c) *Deep Water Paddy*

Long Stemmed Paddies								
Agdar ..	Hbj. Aman	T.S.	Winter	March to May.	Mid December	210	Dirty furrows	Brown
Laki ..	,, 2	,,	,,	,,	Mid December	220	Green	Straw
Gowai ..	,, 3	,,	,,	,,	Mid December	230	,,	,,
Laki ..	,, 4	,,	,,	,,	Mid December	220	,,	,,
Boro								
Boro ..	,, Boro 1	,,	Spring	November	Mid April.	120	Dirty furrows	Brown
Tupa ..	,, 2	,,	,,	,,	,,	124	Green	Straw
Sail boro ..	,, 3		,,	,,	April end	130	,,	,,

Station, Titabar

Awn	Size of paddy			Rice		Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special features ;
	Length (mm.)	Breadth (mm.)	Thickness (mm.)	Colour	Texture					
..	6·0	2·4	..	Red	Abd. white	..	..	..	1920	Resistant to lodging medium size
..	5·2	2·3	..	”	”	..	..	..	1760	
..	7·5	3·2	..	”	”	..	..	..	2080	
..	7·6	2·7	..	”	”	..	..	..	2080	
..	..	..	..	”	”	..	..	..	1760	
..	5·7	2·7	..	White	Transl.	..	..	..	3120	Drought resistant ; non-lodging, coarse
..	7·1	2·6	..	”	”	..	..	..	2560	Medium fine
..	3·4	2·2	..	”	”	..	..	..	2800	Long fine
..	5·6	2·2	..	”	”	..	..	..	2640	Fine
..	7·2	2·5	..	”	”	..	..	..	2640	Medium
..	8·4	2·9	..	”	”	..	..	..	3200	Medium
..	5·6	2·6	..	”	Glut.	..	..	..	·2800	Medium fine

Station, Habiganj

nil	9.0	2·5	..	Light red	Medium hard	..	..	..	..	Grows in 5-7 ft. of water ; fine ong grain
”	8·6	3·0	..	”	”	..	..	..	..	Stands 8-10 ft. of water ; medium, fine
Tawny	7·2	2·9	..	Red	”	..	..	..	..	Stands 10-14 ft. of water : coarse
nil	8·7	3·0	..	Light red	”	..	..	..	..	Stands 8 to 10 ft. of water ; medium
Awned	..	..	..	Red	Abd. white	..	..	..	3120	Early, water requirements less ; coarse
”	..	..	..	White	Transl. ..	..	..	..	3920	Cannot withstand drought ; coarse
Awn less	..	..	..	”	”	..	..	..	2480	High water requirement ; non-shedding medium size.

7. ORISSA

Rice Research

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
Kala kartika ..	T. 442	T. S.	Autumn	June to July	End October	135	Dirty furrows P. tip.	Brown
Senna machakonta	T. 608	,,	,,	,,	Mid October	120	Green P. tip	Straw
Kala kakkudia ..	T. 56	,,	Winter	,,	4th week November	155	Green	,,
Sannakhadi ..	T. 812	,,	,,	,,	,,	,,	Light Gold	Gold
*Badshahbhog ..	T 412	,,	,,	,,	,,	,,	Green	Straw
Safedjira ..	T. 462	,,	,,	,,	,,	,,	Green P. tip	,,
Nandini ..	T. 426	,,	,,	,,	,,	,,	Green	,,
Soruchinnamalli ..	T. 141	,,	,,	,,	,,	,,	,,	,,
Kajalchampa ..	T. 165	,,	,,	,,	2nd week December	175	Green P. tip	,,
Padmakesari ..	T. 90	,,	,,	,,	,,	,,	Green	,,
Special paddies								
Dhala puttia	FR. 13-A	,,	,,	,,	End November	160	,,	,,
Bhetnasia ..	FR. 43-B	,,	,,	,,	3rd week December	180	Dirty furrows	Brown
Lunipatli ..	SR. 26-B	,,	,,	,,	1st week December	170	Green	Straw
Molagu samba ..	Marsh No. 1	Madras	,,	,,	3rd week January	215	,,	,,
Kavingin poothala	Marsh No. 2	,,	,,	,,	End December	190	,,	,,
*Malghanta ..	CTC No. 1	T. S.	,,	,,	2nd week October	120	,,	,,
*Kakharua ..	CTC No. 2	,,	,,	,,	3rd week October	130	,,	,,
*Mahumachi ..	CTC No. 3	,,	,,	,,	1st week October	140	Light gold	Gold
Dalua								
Japanese variety	D. 3	,,	Spring	End December	April end	100	Green	Straw
Japanese variety	D. 4	,,	,,	,,	,,	,,	,,	,,

* Released by Deputy Director, Cuttack Division, before the research scheme

PROVINCE

Station, Cuttack

Awn	Size of paddy			Colour	Texture	Hulling quality	Cooking quality	Percentage increase over control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)							
nil	9·2	2·8	2·0	White	Transl.	Good	Fair	37	2300	Heavy and compact heads
,,	8·6	2·0	·8	,,	,,	,,	Good	..	..	Slightly shedding
,,	9·3	2·9	2·0	,,	,,	,,	..	..	..	
,,	8·9	2·0	1·8	,,	,,	,,	Good	..	2400	Export variety ; good rice
,,	6·3	2·4	1·8	,,	,,	,,	,,	..	..	Fine, short and scented grain
,,	6·0	1·9	1·6	,,	,,	,,	,,	..	..	Fine, short and scented grain
,,	7·0	2·8	1·9	,,	,,	,,	,,	..	..	Heavy yielder on medium type of land
,,	8·3	2·4	1·9	,,	,,	,,	,,	..	..	Good quality heavy yielder
,,	9·4	2·8	2·0	,,	,,	,,	,,	27	3200	Suitable for low lands and broadcasting ; better than Ctc. 3 in yield
,,	8·4	2·0	1·8	,,	,,	,,	,,	17	2400	Heavy yielding : liked by millers ; better than Ctc, 3 in yield
Full	8·4	3·2	2·0	Red	Abd. white	Fair	Fair	..	..	Can withstand submersion for a month
Nil	8·6	3·1	2·1	,,	,,	,,	,,	..	..	Can withstand submersion for 3 weeks
,,	10·4	2·7	2·1	,,	Transl.	Good	Good	..	..	Suitable for saline lands ; doing well in parts of Madras province ; similar to 'Patnai' type of Bengal
,,	7·8	3·1	2·2	,,	,,	,,	,,	..	..	Suitable for low level lands ; strong straw non-lodging. Introduced from Madras province
,,	8·6	2·4	1·8	,,	Transl.	,,	,,	..	..	do.
,,	8·6	2·7	2·0	,,	Abd. white	Average	Average	..	2200	Tall but poor tillering
,,	8·4	2·6	2·0	,,	,,	,,	,,	..	2600	Heavy yielder ; not good for milling
,,	8·4	2·4	1·8	,,	Transl.	Good	Good	..	2400	Heavy yielder
,,	..	..		,,	Fairly hard	,,	,,	33	..	Non-lodging ; erect
,,	..	..	..	,,	,,	,,	,,	,,	..	Less tall than D. 3 otherwise similar

financed by Imperial Council of Agricultural Research was started in 1932.

8. BOM

(a) *Rice Research*

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
Kolamba ..	K. 184	S. P. S.	Autumn	June	September end	110	Green	Straw
Chanchalakolamba	K. 540	Hybrid	Early winter	,,	3rd week October	135	,,	,,
Chibberkolamba ..	K. 42	S. P. S.	Winter	,,	4th week October	145	,,	,,
Zinya	31	,,	,,	,,	End October	148	,,	,,
Zinya	149	,,	,,	,,	,,	148	,,	,,

(b) *Agricultural Research*

Patni	6	S. P. S.	Autumn	June	September end	110	Green	Straw
Panwel	61	,,	Early winter	,,	Mid October	125	,,	Ashy-straw
Fine waksal ..	1	,,	,,	,,	,,	,,	,,	,,
Waksal	207	,,	,,	,,	,,	,,	,,	,,
Bhadas	79	,,	Winter	,	3rd week October	135	,,	,,
Varangal	487	,,	,,	,,	October end	145	,,	,,

(c) *Agricultural Research*

Mugad	161	S. P. S.	Winter	..	3rd week October	140	Green	Ashy-straw
Mugad	81	,,	,,	..	October end	146	,,	,,
Mugad	249	,,	,,	..	,,	150	,,	,,
Mugad	149	,,	,,	..	1st week November	155	,,	,,
Antarsal.. ..	67	,,	,,	..	3rd week October	142	Green P. tip	,,
Antarsal	90	,,	,,	..	End of October	147	Green	,,
Antarsal	200	,,	,,	..	1st week November	156	,,	,,

(d) *Agricultural Research*

Maskati	1315	S. P. S.	Winter	June	Mid November	124	Green	Straw
Jaddu	1061	,	,,	,,	3rd week October	134	,,	,,
Halga	244	,,	,,	,,	End October	144	,,	,,
Halga	1690	,,	,,	,,	Mid November	165	,,	,.

BAY

Station, Karjat

Awn	Size of paddy			Colour	Texture	Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)							
nil	8·2	2·3	..	White	Transl.	Good	Good	..	2100	Early, good yielding for high level lands
,,	7·6	2·2	..	,,	,,	,,	,,	..	2350	
,,	8·1	2·3	..	,,	,,	,,	,,	..	3000	Heavy yielding; midseason variety
,,	8·0	2·1	..	,,	,,	,,	,,	..	2000	
,,	7·8	2·1	..	,,	,,	,,	,,	..	2000	do.

Station, Ratnagiri

nil	8·4	3·1	..	White	Transl.	Good	Good	..	2100	Resistant to paddy moth hairy leaved: broadcast also
,,	8·2	2·6	..	,,	,,	,,	,,	15-20	..	
,,	8·0	2·4	..	,,	,,	,,	,,	..	..	
,,	8·2	2·8	..	,,	,,	,,	,,	..	..	
,,	8·8	3·0	..	,,	Abd. white	,,	,,	15	..	
,,	9·0	2·5	..	,,	,,	,,	,,	16-19	..	

Station, Mugad

Tipped	10·5	3·1	..	White	..	..	..	15	2480	
,,	10·4	3·0	..	,,	..	..	..	11	2500	
,,	10·1	3·0	..	,,	..	..	..	5	2400	
,,	9·8	2·9	..	,,	..	..	..	20	2700	
nil.	9·4	3·1	..	,,	..	..	..	19	2600	
,,	10·0	3·1	..	,,	..	..	..	15	2500	
Tipped	9·8	3·0	..		..	..	..	..	..	

Station, Kumta

nil	9·0	3·0	..	White	..	..	..	..	..	Useful for parboiling
,,	8·6	3·6	..	Red	..	..	..	15-20	..	Early, useful for coastal areas and high level lands
,,	8·3	3·5	..	,,	..	Good	Fair	,,	..	Low lying areas of Kumta resistant to silver shoot
,,	8·4	3·5	..	,,	..	..	..	,,	..	For low lying transplanted rice area of upghat

9.

Rice Research

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
Kangni ..	27	S. P. S.	...	June to July	October end	95	Green	Straw
Prong ..	36	,,	..	,,	Mid. November	105	Green P. tip	,,
Jajai sugdasi ..	77	,,	..	,,	Early November	100	,,	,,
Bengalo ..	A	T. S.	..	,,	,,	,,	,,	,,
Kangnix Torh	16	Hybrid	..	,,	October end	95	Green	,,
Silver Jubilee ..	28	,,	..	,,	Mid. October	90	Light dirty furrows	Dark brown
Sonabari ..	B	S. P. S.	..	,,	Mid. November	105	Green	Reddish brown
Sada Gulab ..	C	,,	..	,,	,,	,,	,,	,,

SIND

Station, Larkana

Awn	Size of paddy			Colour	Texture	Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)							
nil	10·0	2·6	2·1	White	Transl	Good	Poor	20	1000	Specially for parboiling, largely grown.
Tipped	9·3	2·4	2·0	,,	,,	Good	Good	30	1200	Late maturing, scented rice
nil	9·3	2·4	2·0	,,	,,	,,	,,	14	1200	Good quality rice, does not lodge, scented
Tipped	9·3	2·4	2·0	,,	,,	,,	,,	20	1500	Do.
nil	10·2	2·9	2·2	,,	,,	,,	Fair		2000	Useful for saline lands ; yields as good as Kangni
,,	9·8	2·4	1·9	,,	Medium	Fair	,,	10-15	2500	Superior to Kangni
Tipped	10·4	2·5	2·0	,,	Transl	Good	Good	16	1600	Scented, superior to Prong 36
,,	10·3	2.5	2·0	,,	,,	,,	,,	23	1600	Non-lodging, scented rice ; for low lands

10. THE

Rice Research

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
Jhona	349	T. S.	Autumn	June to July	Mid. October	130	Green	Straw
Mahlar ..	346	,,	,,	,,	End of September	120	,,	,,
Palman suffaid ..	246	,,	,,	,,	Mid. October	130	Green P. tip	,,
Basmati ..	370	,,	Winter	July	3rd week November	140	Green	,,
Do. ..	381	,,	,,	,,	,,	,,	,,	,,
Mushkan ..	41	,,	,,	July to August	End of November	,,	Light gold	Gold
Do ..	7	,,	,,	,,	,,	,,	Gold	Dark gold
Sathra ..	278	,,	Autumn	May to August	Mid. August to end September	105	Gold	Dark gold

PUNJAB

Station, Kalashah Kaku

Awn	Size of paddy			Colour	Texture	Hulling quality	Cooking quality	Percentage increase in yield over control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)							
nil	9·4	2·5	1·9	White	Transl	Fair	Fair	..	2700	Compact panicle; stands some salinity.
Tend	9·9	2·7	1·9	,,	,,	,,	,,	..	2700	
nil	9·7	2·0	1·7	,,	,,	Good	Good	..	2400	Long heads
Tend	9·7	2·1	1·8	,,	,,	,,	,,	..	2000	Good quality scented rice, known as Dehradun Amritsari in trade; very much prized for its cooking qualities
,,	,,	,,	,,	,,	,,	,,	,,	..	2300	Higher yielding than 370
nil	9·4	2·2	1·8	,,	Hard	,,	,,	..	2200	Threshing difficult slightly scented very long panicle
,,	9·0	2·3	1·9	,,	,,	,,	,,	..	2400	Easy to thresh, strongly scented, long panicle
Full-awned	9·3	2·5	1·8	,,	Abd. white	Average	Poor	..	1800	Useful for reclaiming usar lands

11. HYDERABAD

Main Agricultural Experiment

ame of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
American paddy	H. S. 1	S. P. S.	Winter	June	October November	150	Green	Straw
Kitchni samba ..	,, 35	..	,,	,,	November	175	,,	,,
Guthi Kusuma ..	,, 38	,,	,,	,,	..	180	..	,,
Gandharnikoo ..	,, 8	,,	Autumn	..	September	120	Green P. tip	,,
Rajahansa ..	,, 12	,,	Spring	December	March	120		
			Autumn	June	September	135	Green	,,
			Spring	December	March	135		
Gowdalu ..	,, 21	,,	Autumn	June-July		120	Light gold	Rich gold
			Spring	December January	March April	120		
Amritsari ..	,, 22	,,	Autumn	June to July	October	120	Green	Straw
			Spring	December January	March April	120		
Sukhadas from Sind	,, 27	,,	Autumn	June to July	September October	120	Green P. tip	,,
			Spring	December January	April	120		

(DECCAN)

Station, Himayatsagar

Awn	Size of paddy			Colour	Texture	Hulling quality	Cooking quality	Percentage increase yield over control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)							
nil	10·6	2·3		Dull white	Transl	Good	Good	..	1500 2000	Compact panicle
,,	7·3	2·3	..	White	,,	,,	,,	..	2500	May be the same as Geb. 24 of Madras. Great demand for consumption by middle class
,,	7·7	2·7	..	,,	,,	,,	Satisfactory	..	2500 2800	Coarse trade rice
,,	8·3	2·8	..	,,	Abd. white	..	..	..	1000 1200	Weak straw ; compact heading but popular
,,	9·9	2·6	..	,,	Transl	,,	Good	..	1500 1800	Short duration paddy commanding a large area
Tend	10·9	2·2	..	Very brown red	,,	,,	,,	..	1500 1800	Non-lodging ; popular
,,	7·3	2·3	..	White	,,	,,	,,	..	1000	Good 'pulao' rice
Awned	9·5	2·4	..	,,	,,	,,	,,	..	2000	Does not lodge

12. MY

Naganhalli

Name of variety	Number	Origin	Agricultural group	Time of sowing	Time of harvest	Total duration (days)	Colour of lemma	
							Fresh	Ripening
Kembhuti	S. 67	S. P. S.	Winter	July-August	December end	175	Gold	Dark brown
Kaddi ..	,, 139	,,	,,	,,	,,	180	Green	Straw
Nagpur sanna ..	,, 246	,,	,,	,,	1st week	135	,,	,,
	X. 18	Hybrid	,,		November end	160	,,	,,
	X. 194	,,	,,	,,		160	,,	,,
Kempu sanna ..	S. 476	S. P. S.	,,	July	End November	160	Gold	Brown
Alur Sanna ..	S. 197	,,	Autumn	,,	End October	135	Green	Straw
Coimbatore sanna	,, 661	,,	Winter	,,	End November	160	,,	,,

Hebbal

Bangarakaddi ..	,, 705	S. P. S.	Summer	December	April	120	Gold	Reddish brown
Halubbalu ..	,, 317	,,	,,	,,	,,	,,	Green	Straw
Chintamani-sannabhatte	,, 547	,,	,,	,,	,,	,,	,,	,,

13.

	T. E. B. 1	S. P. S.	Summer	May	October	180	Light gold	Reddish brown

SORE

Farm

Awn	Size of paddy			Colour	Texture	Hulling quality	Cooking quality	Percentage increase yield over control	Yield per acre (lb.)	Special features
	Length (mm.)	Breadth (mm.)	Thickness (mm.)							
Tend	..	..	..	White	Transl.	Good	Good	..	3000	Slight shedding; slight lodging
nil	..	..	..	,,	,,	,,	,,	..	2800	Less shedding
Tend	..	..	..	,,	,,	Average	,,	..	1700	Fine ; weak straw
nil	..	..	..	,,	,,	Good	,,	..	3000	Good quality rice high yielding
				,,	,,	,,	,,	..	3000	Do.
Tend	..	..	..	,,	,,	,,	,,	..	2500	Suitable for poor fields ; lodges
,,	..	..	..	,,	,,	Average	Average	..	2600	Grown under tanks ; slight lodging
nil	..	..	..	,,	,,	Good	Good	..	3000	Good quality ; high yielding
Farm										
Tipped	..	..	..	White	Abd. white	Average	Average	..	..	Non-lodging
nil	..	..	..	,,	,,	..	..	..	..	
..	..	..	..	,,	,,	Transl	Good	Good	..	
Travancore										
Tip	8·0	3·5	2·5	White reddish tinge		..	..	15-20	2500	Double grained, alkali resistant, non-shedding, non-lodging

EXPLANATORY NOTE FOR APPENDIX I

All the improved strains available with the rice botanists concerned are listed here. The full descriptions of these strains as per the schedules prescribed in the rice variability paper [Hutchinson and Ramiah, 1938] are not yet available but the more important morphological and agricultural characters are reported here. Under the column, origin, three terms have been used, namely hybrid, single plant selection (S.P.S.) and type selection (T.S.). Hybrids are those synthesised by crossing different varieties or pure lines for improvement in definite characteristics. Single plant selections are those evolved by ordinary progeny selection methods from the bulk crop of the particular varieties grown extensively in the tract. Type selections are those first isolated from the bulk crop for variations in morphological characters and then tested for yield. The two latter correspond to the intravarietal and intervarietal selection described in Chapter II of Part II. The acre yields recorded refer to those either obtained at the agricultural research stations or in yield trials conducted in cultivators' fields where such trials have been carried out. In the latter case the percentage increase in yield over the control has also been included. In several cases the percentage yield increase over control is not available and this might be due to regular yield trials in the cultivators' fields not having been carried out. In some cases, as for instance, in the case of Assam, strains have been issued even when there was no definite increase in yield over the control because of certain other characteristics like uniformity of produce, desirable colour of rice, slight earliness in duration, etc. Due to dislocation resulting from war conditions, information on Burma strains could not be obtained.

APPENDIX II

GENIC SYMBOLISATION

(After Kadam and Ramiah).

Alphabetical list of basic symbols proposed and characters expressed by them

	Gene symbol	*Character expression*
A		
	A	Anthyocyanin gene (basic)
	An	Presence of awns
	Anb	Black awns
	Anbr	Brown awns
	Anp	Purple awns
	Anr	Red or pink awns
	Ap	Apiculus coloured
	au	Auricle absent
	Aup	Auricle coloured purple
	Ax	Leaf axil coloured
B		
	bc	Brittle culms
C		
	C	Chromogen gene
	Ce	Resistance to *Cercospora oryzae* Miyake
	chl	Chlorina seedlings
	cl	Clustering of spikelets
	Cp	Coleoptile coloured purple
D		
	d	Dwarf plant
	Di	Dilutes anthocyanin pigment
E		
	ef	Floating habit of plant
	er	Erect habit of plant
	Er	Prostrate habit of plant
	Es	Spreading habit of plant
	Ex	Exsertion of the panicle
F		
	f	Sterility (basic letter)
	fan	Awned sterile
	fas	Asynaptic sterile
	fb	Barren sterile
	fcl	Curved leaf sterile
	fdp	Degenerated pistil
	ffs	Female sterile
	fl	Flowering duration of the plant
	fm	Male sterile
	fnd	Non-dehiscent anthers
	fo	Completely sterile
	fog	Narrow leaf, open glume, sterile
	fp	Paleaceous sterile
	fs	Semi-sterile
	fsh	Shrivelled stamens
	fsl	Slender semi-sterile
	fst	Staminoidal sterile
	fw	White sterile
G		
	G	Short glume
	Gp	Glume coloured purple
	Gr	Glume coloured red
H		
	H-b	*Ripening black lemma and palea
	H-br	Ripening brown lemma and palea
	Hc	Extensifier of purple pigment on lemma and palea
	Hf	Blackish brown furrows in lemma and palea
	Hg	Green lemma and palea

---

*Ripening character is indicated by a dash between the major gene H and the secondary letter.

	Gene symbol	*Character expression*
	H-go	Ripening gold
	hm	Mottled distribution of brown pigment in lemma and palea
	Hpb	Piebald distribution of brown pigment in lemma and palea
	H-p	Ripening purple lemma and palea
	hpt	Lemma and palea parted
	H-r	Ripening red lemma and palea
	H-t	Ripening tawny lemma and palea
	Ht	Controls pattern of pigment in lemma and palea in the absence of *Ih*
	h-w	Ripening white lemma and palea
	Hy	**Yellow lemma and palea**
I		
	I	**Inhibitor (basic letter)**
	Ian	**Inhibits awn development**
	Id	**Inhibits tallness, making plants dwarf**
	Ifl	**Inhibits early flowering**
	Ih	**Inhibitor of gold or orange lemma and palea**
	Ilp	**Inhibits purple pigment in leaf-blade**
	Ish	**Inhibits shattering of grain**
	It	**Inhibits tall growth**
	Itf	**Inhibits tough shelling**
J		
	Jp	**Junctura coloured purple**
K		
	Kl	Spikelet (grain) length—short
	kl	Spikelet (grain) length—long
	Km	Spikelet (grain) length—medium
	Kr	Spikelet (grain) shape—round
L		
	l	Lutescent seedlings
	la	Lazy or ageotropic plant
	Ld	Lodging of culms
	Le	Resistance to *Leptosphaeria salvini* Cattaneo, (Syn. *Helminthosporium sigmoideum* Cavara)
	lg	Absence of ligule
	Lgp	Ligule coloured purple
	Lh	Leaf hairiness
	Lmp	Leaf margin coloured purple
	Lp	Leaf blade purple
	lro	Rolled leaves
	Lsp	Leaf sheath coloured purple
	Lsv	Leaf sheath coloured purple in vascular bundles only
	ltw	Twisted leaves
	Lx	Lax panicle
	Lxp	Leaf axil coloured purple
	vLv	Leaf striped purple
M		
	mp	Many pistils
N		
	ne	Sinuous neck of the panicle
	Np	Node coloured purple
	Ntbr	Internode coloured brown
	Ntp	Internode coloured purple
	Ntr	Internode coloured light purple
	Ntv	Internode possessing purple linings
O		
	O	Scentedness of rice
	Om	Resistance to *Ophiobolus miyabeaunus* Ito and Kuriyobashi (syn. *Helminthosporium oryzae* Cattaneo)
	Op	**Vitreous (as against opaque) grain**

	Gene symbol	*Character expression*
P	*Pbr*	Pericarp coloured brown
	Pi	Resistance to *Piricularia oryzae* Briosi and Cavara
	Pr	Pericarp coloured red
	Prp	Pericarp coloured purple, brown in the absence of *A*
R		
	Rp	Roots coloured purple
S		
	S	Non-clustering of grain
	Sc	Clustering (dominant) of grain
	Sh	Shattering of grain
	Sp	Stigma coloured purple
	sp	Spreading panicle
	sty	Stunted yellow plant
	Sm	Septum coloure purple
T		
	T	Height of plants (tallness)
	Tf	Tough shelling of lemma and palea
	tp	Tip burn yellow
V		
	v	Virescent seedling
	vr	Variegated seedlings
W		
	w	Albino seedlings
	wb	Abdominal white spot of kernel
	wx	Glutinous endosperm
Y		
	y	Lethal yellow seedlings
Z		
	x	Zebra-striped seedlings

APPENDIX III

GLOSSARY OF VERNACULAR TERMS USED

Aghani	A term used in United Provinces for a short duration rice grown in summer and harvested towards the end of August
Aman	A term used in Assam and Bengal for the rice crop sown on low-land in March to May and harvested in December to January
Asra	A term used in Assam and Bengal for the rice that is grown in areas which are flooded upto 6 to 8 feet of water
Aus	A term used in Assam and Bengal for early rice crop sown on high-lands in April to May and harvested in August or September
Ayurveda	Medical Science of ancient Hindus
Beali	A term used in the Orissa Province to denote early rice crops
Bhadoi	Short duration rice varieties which are harvested in September
Bhils	Low depressions in the deep water areas from which the *boro* crop is irrgated
Biasi	A system of ploughing with a country plough the broadcast rice crop to check weeds and stimulate growth
Boro	A term used in Assam and Bengal for a crop sown in swamps in January-February and harvested in April or May
Dalua or Dalwa	A term used for the second short crop in the Telegu districts of Madras and in Orissa. The term is used to denote both the crop season and the varieties grown then
Dorsa	The heavy clay soil types met with in the Central Provinces
Ghora	Name of a short duration rice grown in Bihar
Gundhi	The Hindi name for rice fly
Jhum	A system of primitive hill cultivation after clearing jungles
Jorhan	Wild rice found in the deep water areas of Assam and Bengal
Kar	The short duration first crop in the Tamil districts. The term is used both for the season and for the varieties grown then
Kharga	Wild rice found in the Central Provinces. Synonymous to *Jorhan*
Kharif	A term used all over Northern India for the monsoon season and for the crops grown then
Laghu	A term used in Orissa to denote short duration rices
Matasi	Light soil types met with in the Central Provinces
Modan	A term used to denote the dry sloping lands of Malabar, Madras, on the top and sides of hills dependent absolutely on South West monsoon for its water supply. The term is also used to denote the rice varieties grown on such lands
Malguzars	Term applied to land lords in Central Provinces
Pairugali	The corn wind that blows in the northern districts of Madras Province during February to April
Patlands	Low lying lands in Orissa where stagnates during the monsoon season water
Peddapanta	A term used in the Telegu districts of Madras to denote the main crop season—July to December
Rabi	A term used for the winter cropping in North India
Samba	The long duration main crop or the second crop in the Tamil districts of Madras
Sarad	Winter rices
Sarva	A term used in the Telegu districts of Madras for the first long term, June to December
Sawai	System of giving seed on loan to be returned with interest in kind
Takkavi	Loan issued by the Government to landlords for agricultural purposes
Udu	A particular system of rice cultivation in Tanjore, Madras where two varieties of rice, a short duration and a long duration one are grown together mixed
Utera	A pulse sown in the standing crop of rice before harvest

APPENDIX IV

A LABORATORY METHOD FOR DETERMINING COOKING VALUE OF RICE

A water bath made out of kerosene tin is used. The dimensions of the water bath are about nine inches by nine inches by ten inches. This carried a lid with eight perforations to take in metallic or glass tubes (the latter preferable). The external diameter of the glass tube is about one-and-a-half inches and the length is about seven to eight inches.

It is necessary always to take the same definite quantity of rice for all cooking trials as it will enable easy recording of readings with the apparatus described above. A definite quantity of rice (20 gm.) is taken for the trials and the water taken is four times the weight of rice ; that is, 80 c.c. of rain water is always used. The rice is soaked in water for ten minutes before putting into the bath. The water of absorption and adsorption are determined and while adding water for final cooking, this quantity is deducted. Cooking is taken as complete when the hardness in the grain just disappears ; this can be found out by pressing the cooked rice between the thumb and the fore-finger from time to time, during cooking.

The tube with the cooked rice is then weighed and the weight of the cooked rice determined. The weight of the cooked rice increases with the rate of absorption of water.

After complete cooking, the excess water is drained off and the volume of the liquid is determined ; to this is added the volume of water that escapes as steam during the cooking period.

The difference between the volume of water originally taken for cooking and the volume of the drained-off liquid (*kanji*) represents the volume of water used up for cooking.

Data regarding expansion of rice in volume on cooking are obtained by recording the volume of water displaced by putting the cooked rice in a known volume of water in a measuring jar. To get accurate readings the following method has been evolved from this laboratory.

The volume of 20 gm. of rice is recorded, which is generally 14 c.c. by water displacement method. The rice is put into the glass boiling tube, and the tube is then fitted with a rubber stopper carrying a long graduated glass tube (a broken burette tube with the narrow end removed can be cut and made to serve the purpose). Water is poured into the tube till it fills the boiling tube and rises up a little in the graduated tube until it occupies the zero c.c. mark on the tube. The tube is preferably numbered and the quantity of water added for that particular tube is recorded ; once this data is recorded for a particular tube, there is no need to record such readings for subsequent cooking trials, as the quantity and volume of rice are always same. A number of tubes may be taken and similar data may be obtained for each tube. The position of the bottom surface of the rubber stopper is marked on the glass tube with a glass etching pencil. This mark serves to bring the stopper to the same level for future readings. At the time of cooking, the rubber stopper carrying the burette tube is removed. The data mentioned above are recorded before starting the cooking experiments.

When cooking is complete and the excess water drained off, the rubber stopper with the burette tube is now fitted on to the tube and the bottom surface of the rubber stopper is adjusted to coincide with the mark already made on the tube when determining the water required to fill up to the zero c.c. mark on the burette tube, with 20 gm. of rice; this same quantity of water for the particular tube is now added through the burette tube. Any air bubbles adhereing to the bottom surface of the stopper are carefully removed by tilting the tube several times. The position of water level on the burette tube indicates the expansion undergone by 20 gm. of rice. By this method readings can be made accurate to 0.1 c.c.

L15ICAR—775—21-4-53—GIPS

ERRATA

Page	*Line*	*For*	*Read*
(i)	7	hetrosis	heterosis
(v)	2	Fordword	Foreword
(ix)	Fig. 2	Phillipines	Philippines
Plate I	1	*O. echingers*	*O.eichingeri*
6	4	Hygrorphiza	Hygroryza
6	5	general	genera
6	11	Hygrorhiza	Hygroryza
9	1	tar	far
9	29	for a *Oryza*	for *Oryza*
9	42	mountaneous	mountainous
10	29	F, S_2	F_1s
14	10	case	ease
14	18	straited	striated
22	35	fertilisation The	fertilisation. The
25	35	late-found	late-formed
26	32	in tact	intact
31	24	breeds	breeders
32	3rd from bottom	removeing	removing
33	1	percentages	percentage
34	3rd from bottom	F_{25}	F_2
43	3	F	F_1
44	last	*intravarie*	intra-varietal
48	Map	Maruter	Maruteru
49	21	*p*H	*p*H
57	last	th	the
61	13	Marute u	Maruteru
71	23	*crop*	crop
79	14	*bora*	*boro*
80	1	very	vary
81	38	but	out
90	last	are	area
93	3rd from bottom	*Phaseols*	*Phaseolus*
101	30-31	receive requirements	receive their requirements
101	3rd from bottom	*Delete words* 'This is a very sound system as it prevents the foisting of'.	
101	2nd from bottom	*Delete words* 'more prolific'.	

Page	*Line*	*For*	*Read*
101	last	ascertaining the	ascertaining the superiority of the new kind.
105	36	that a purple	that purple
108	last	palen	palea
111	26	gave range	gave a range
111	2nd from bottom	*Delete words* ‘confirming the recessive nature of the mutation’.	
111	3rd from bottom	*Delete words* ‘The gene controlling the’.	
113	10	reported of a	reported a
113	39	F	F_1
114	2nd from bottom	rtex	cortex
114	5th from bottom	iines :	lines
115	2nd from bottom	F and F	F_3 and F_4
116	last	st ucture	structure
117	11	F	F_2
122	20	ibib	ibid
122	5th from bottom	F_1	F2
122	7th from bottom	purp	purple
124	11	F_1 and F_2	F2 and F3
125	7	hairilness	hairiness
127	4	Pathasarathy	Parthasarathy
127	6	respectively counts. in segreating	respectively. Counts in segregating
130	Table	♂♂	♂
130	2nd para, 12th line	material	maternal
131	3rd from bottom	licated	plicated
131	20	materially	maternally
133	13th from bottom	*Pennisetun*	*Pennisetum*
134	5	governing	governed
140	9	h	H^h
140	5th from bottom	Dav	Dave
141	18	Ih	ih
142	15th from bottom	F_2	F_3
144	18	and either	that either
144	2nd from bottom	dehybrid	dihybrid

Page	*Line*	*For*	*Read*
149	10th from bottom	10·95	10·75
151	13th from bottom	tetratalogical	teratalogical
152	last	F	F_1
152	2nd from bottom	d rk	dark
Plate XXI	1 (caption)	Coimhatore	Coimbatore
160	2, 3, 4, 6, 7, 8, 9, 12, 14, 16	caryposes	caryopsis
163	18	AD_c	AB
167	30	F_8	F_3
167	30	hundered	hundred
168	31	F	F_1
170	7	F	F_1
170	14	a O_b	O_b O_c
171	3rd from bottom	variamility	variability
174	9th from bottom	fas n	fas_b
174	8th from bottom	tobacca	tobacco
177	4th from bottom	(100 : 940)	(1002 : 940)
181	3	F	F_2
182	27	hpothesis	hypothesis
185	13th from bottom	T, T_2	T_1 T_2
187	5th from bottom	lodying	lodging
187	13	week	weak
187	2nd from bottom	strengths	strength
191	6	Ld	ld
193	Fig. 5 (part 4)	*O.Coarctata*	*O.coarctata*
194	12	rogueing	roguing
194	13	may, also	may also
195	24	F_2	F_1
196	8th from bottom	*officinals*	*officinalis*
197	24	submered	submerged
204	2	salt and	on the
212	23	interitance	inheritance
213	4th from bottom	F_1	F_1s
213	6th from bottom	inmportant	important
214	last	F	F_1
219	9	pathoenically	pathogenically
219	12	*P.oryza*	*P.oryzae*
219	15	*Elusine*	*Eleusine*
220	36	Sheathes	sheaths
222	8	Outside of Italy	Outside Italy
222	25	slcerotia	sclerotia

Page	*Line*	*For*	*Read*
223	27	elongaged	elongated
225	6	will control	with controlled
225	20	*schoenobium*	*Schoenobius*
225	28	planning	planting
226	1	week	weak
227	4th from bottom	of tobacco	of tobacco.
229	7th from bottom	Pnase	Panse
231	8th from bottom	tillers very	tillers is very
239	18	l_g	**lg**
239	24	c	cl
239	6th from bottom	W_x	w_1
239	7th from bottom	as case	a case
240	6	14, 7	14·7
240	14	puple	purple
240	17	F_8	F_2
245	21	sinmple	simple
246	10th from bottom	genic	genetic
247	27	naploid	haploid
247	10th from bottom	killougn	Killough
252	Serial No. 23	matation	mutation
253	Serial No. 36	spon-neous	spontaneous
254	Serial No. 60	slonder	slender
259	10	oroximal	proximal
261	4	extinet	extinct
264	14th from bottom	interspecies	interspecific
264	17	*echingeri*	*eichingeri*
265	25	F	F_1
267	1	anatural	natural
Plate XXX	1 (caption)	coimbatur	Coimbatore
284	15	PH	*p*H
288	5th from bottom	*Delete words* 'level of the'	
290	12th from bottom	phosphates available,	phosphates, available
293	13	menance	menace
294	17	science	sciences
295	5th from bottom	*Hygene*	*Hygiene*
295	ref. 10	1932-33 and 1927-28	1927-28 and 1932-33
297	ref. 9	low and	lowland
298	ref. 15	genus	genus,
300	ref. 27	Rontgen	Roentgen
300	ref. 34, line 1	un......urable	unfavourable
300	ref. 34, line 2	A	*Abs.*

Page	*Line*	*For*	*Read*
300	ref. 34	fcertain varietie	of certain varieties
301	ref. 21	Mad as	Madras
301	ref. 23	beard dness	beardedness
302	ref. 8	caryopses	caryopsis
302	ref. 13	studiefs	studies
302	ref. 17	methods emascultiang	methods of emasculating
302	ref. 21	*6.Sativa*	*O.sativa*
303	ref. 4	*Orysa*	*Oryza*
304	ref. 2	phasio	phasic
304	ref. 4th from bottom	*Acod.*	*Acad.*
305	ref. 16	*ndian*	*Indian*
306	ref. 8th from bottom	poly ploidy	polyploidy
307	ref. last	Sort	Soil
308	ref. 21	*Amed.*	*Amer.*
308	ref. 30	rost	rot
314	Column 1, line 5	Dand In	Daud Ind
315	5th from bottom	fin	fine
	3rd from bottom	rsch	rich
	17th from bottom	ong	long
	3	coloure	coloured

TECHNOLOGICAL RESEARCH I... LIBRARY MYSORE

GIPD—M—171C of A R—5-12-53—775

1/5/87

CHECKED
2008

VERIFIED
2013

CFTRI LIBRARY, MYSORE - 570 020

Acc. No. 2960 Call No. J, 31 ; 3 ; 3

Please return this publication on or before the last due date stamped below to avoid incurring overdue charges.

To be issued from:

DUE DATE	RETURNED ON	DUE DATE	RETURNED ON
16.12.09	3.12.09		
9/3/11	21.3.11		

J,31:3;3
o. J~~3816 L3~~
AIAH
ding and